

AMSR-E Polarimetric Scanning Radiometer System Update

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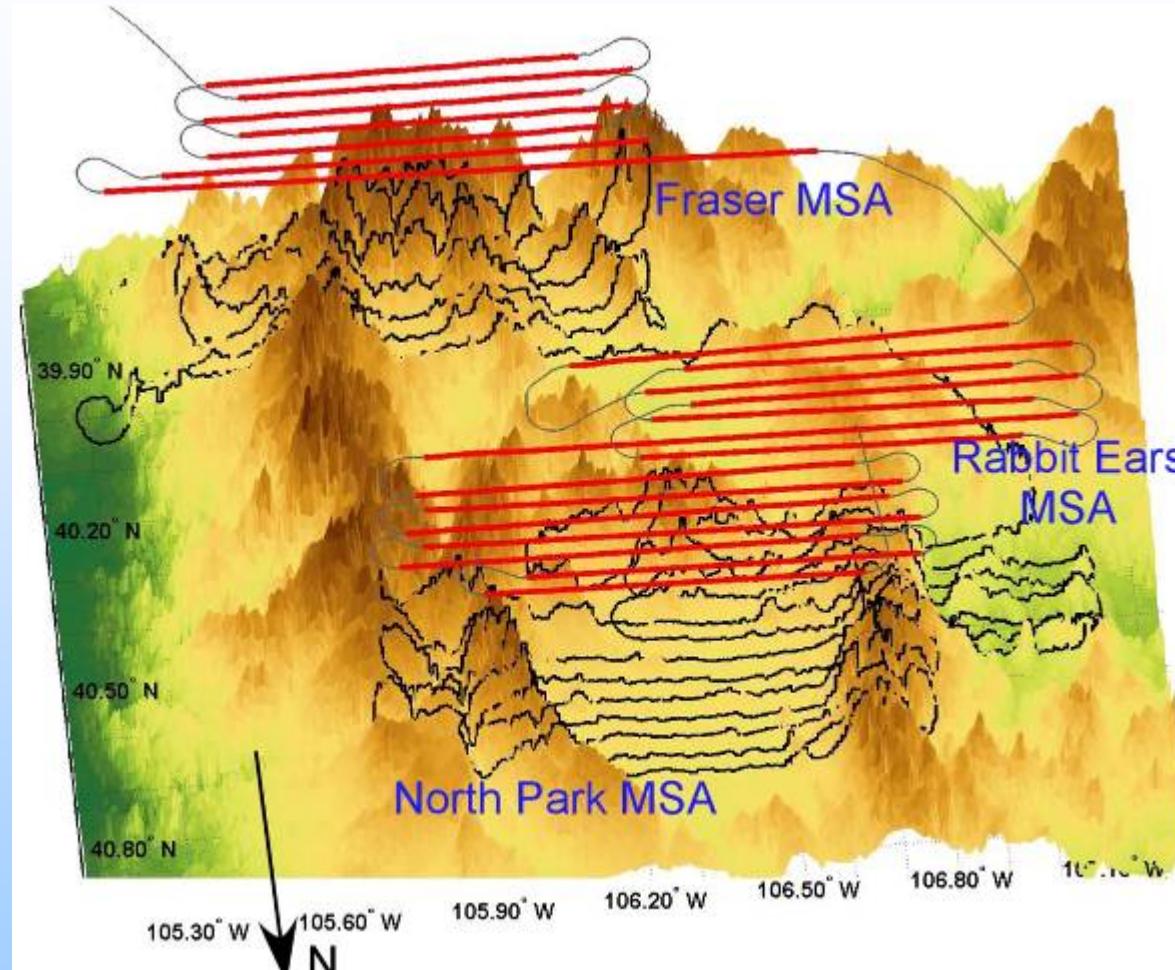
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⁵ Zel Technologies, Boulder, CO, USA

Major Activities in 2005

- Cold Land Processes Experiment (CLPX) data processing
- SMEX04/NAME
- AASI04
- RF interference mitigation studies using PSR/CXI on NASA/JSC WB-57F
- PSR/S flights on General Atomics ASI Altair UAV

Cold Land Processes Experiment

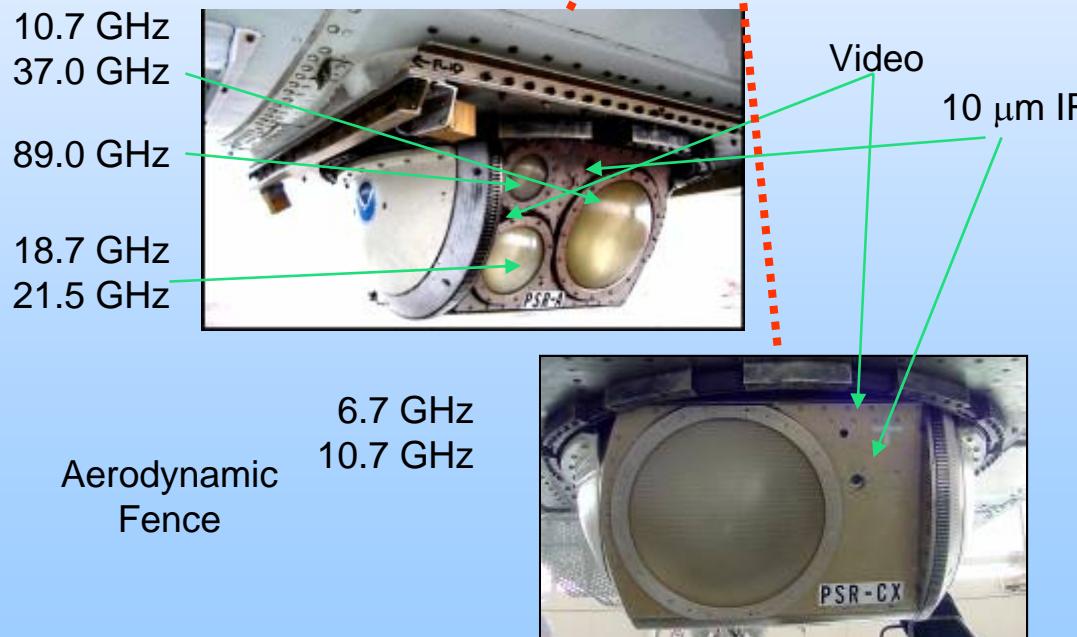


3D view of the CLPX Mesoscale Study Areas (MSA) that were sampled during February 2002, February 2003 and March 2003. Flight lines (red), flight lines projection onto the ground (black)

CLPX configuration



	CLPX02	CLPX03A	CLPX03B
Aircraft	DC8	P-3	P-3
Scanhead	PSR/A	PSR/A	PSR/A PSR/CX





CLPX Data Summary



Exp. Name	MSA	Date	Obs. Times (UTC)	Tot. # of Flt. Lines	Flt. Alt. (km AGL)	3 dB Spatial Resolution Range (m) @ 37, 89 / 10, 18, 21 GHz
CLPX02	RE	2/19/02	21:18-22:35	7	2.34	88 / 308 – 209/728
	FM	2/21/02	16:45-18:49	7	2.10	55 / 191 – 234/812
	NP	2/23/02	16:57-18:34	7	2.10	54 / 184 – 203/708
CLPX03A	NP	2/22/03	18:35-20:35	7	3.93	184 / 642 – 334/1161
	NP, RE, FM	2/23/03	17:35-21:37	21	2.18	65 / 229 – 215/749
	NP, RE	2/24/03	20:30-23:05	14	2.22	71 / 246 – 206/718
	NP, RE, FM	2/25/03	17:30-21:00	21	2.18	65 / 229 – 215/749
CLPX03B	NP, RE, FM	3/25/03	17:50-22:05	21	2.18	65 / 229 – 215/749
	NP, RE, FM	3/30/03	18:10-22:30	21	2.18	65 / 229 – 215/749
	NP, RE, FM	3/31/03	17:50-21:50	21	2.18	65 / 229 – 215/749

Principal Investigator: Don Cline

PSR Team: A.J. Gasiewski, B.B. Stankov, B.L. Weber

Quicklook data can be found at <http://www.etl.noaa.gov/data/psr/clpx03/>

**Total flight hours = 29.7
of flight lines = 147**

PSR/A & PSR/CX Parameters

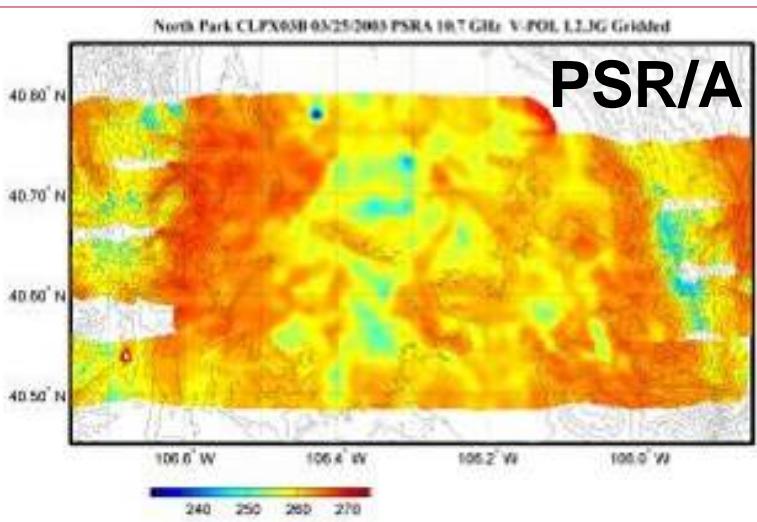
- PSR is the first operational airborne multi-band conically-scanning imaging radiometer.
- The PSR was designed for a variety of high-resolution environmental remote sensing purposes and was uniquely suited for CLPX studies.
- The most recent PSR hardware improvement permits simultaneous use of multiple PSR scanheads on a single aircraft to provide imagery at all of the AMSR-E bands.

Frequency (GHz)	Scanhead	Polarization	Beamwidth ¹ (°)	ΔT _{rms} ² (K)
5.8-7.5	PSR/CX ³	v,h,U,V	10	0.2
10.6-10.8	PSR/CX ³ PSR/A	v,h,U,V	7	0.4
			8	0.6
18.6-18.8	PSR/A	v,h,U,V	8	0.3
21.4-21.7 (H ₂ O)	PSR/A	v,h	8	0.4
36-38	PSR/A	v,h,U,V	2.3	0.5
86-92	PSR/A	v,h,U	2.3	0.6
10 μm (IR)	PSR/A	unpolarized	7	0.2

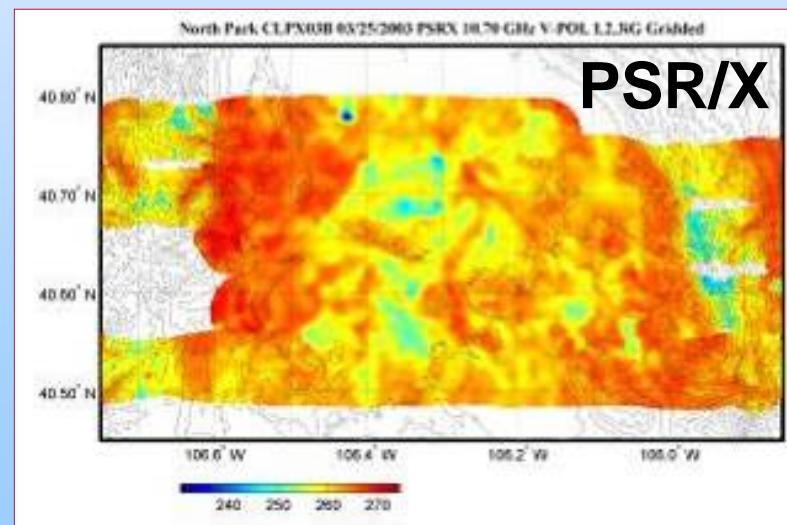
¹ Half-power beamwidth; ² 18 msec equivalent integration time, v & h; ³ Multiple Sub-bands for interference mitigation

PSR/A - PSR/CX Intercomparison

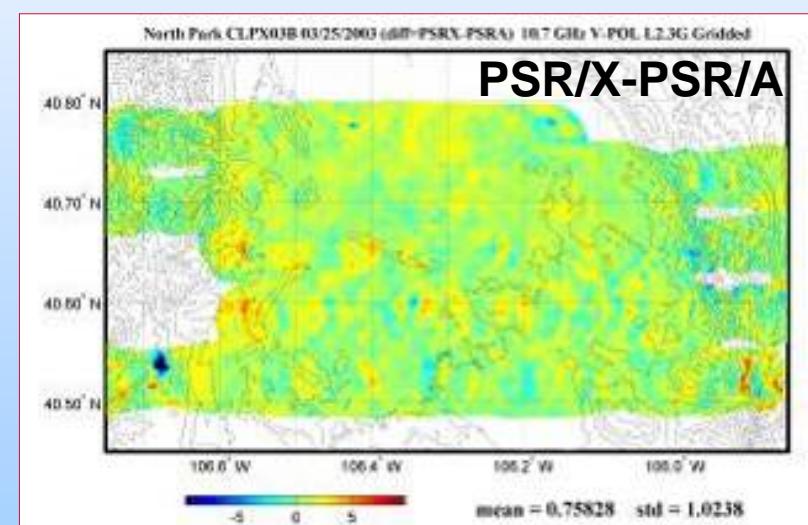
10.7 GHz V-polarization, North Park



Mean_{Diff} = 0.758

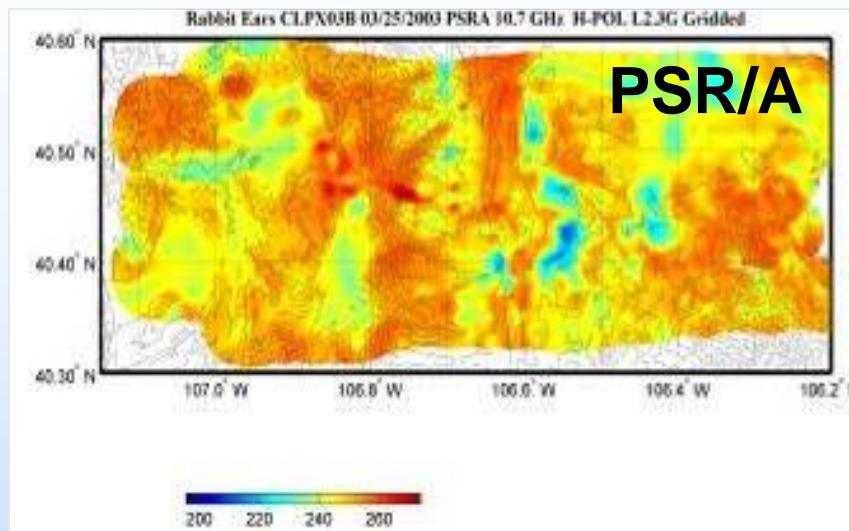


Std_{Diff} = 1.024

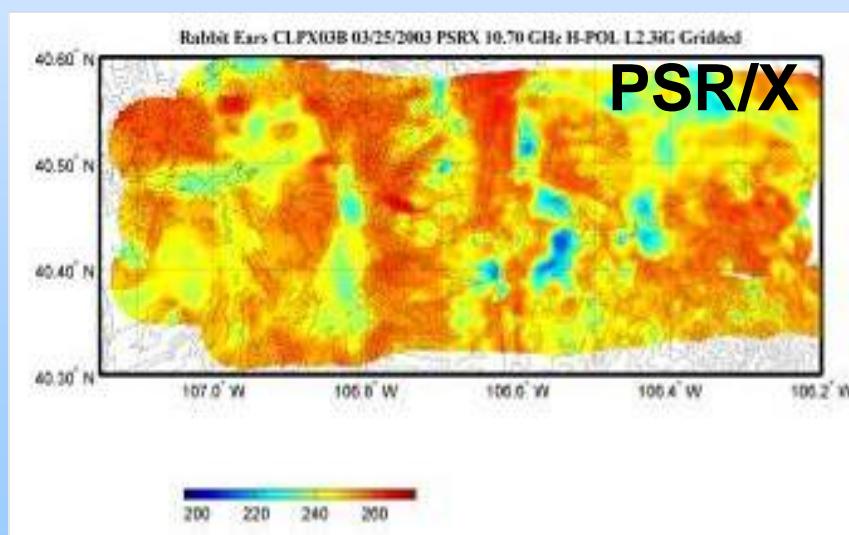


PSR/A –PSR/CX Intercomparison

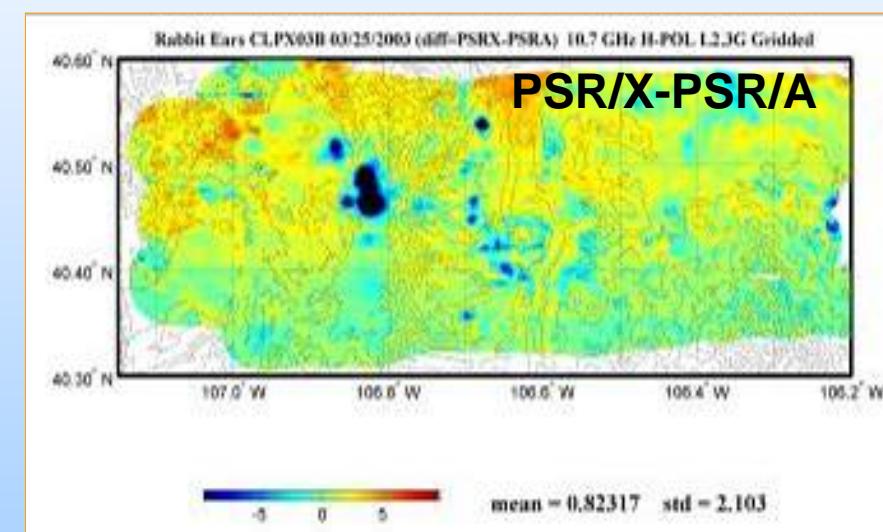
10.7 GHz H-polarization, Rabbit Ears



Mean_{Diff} = 0.823

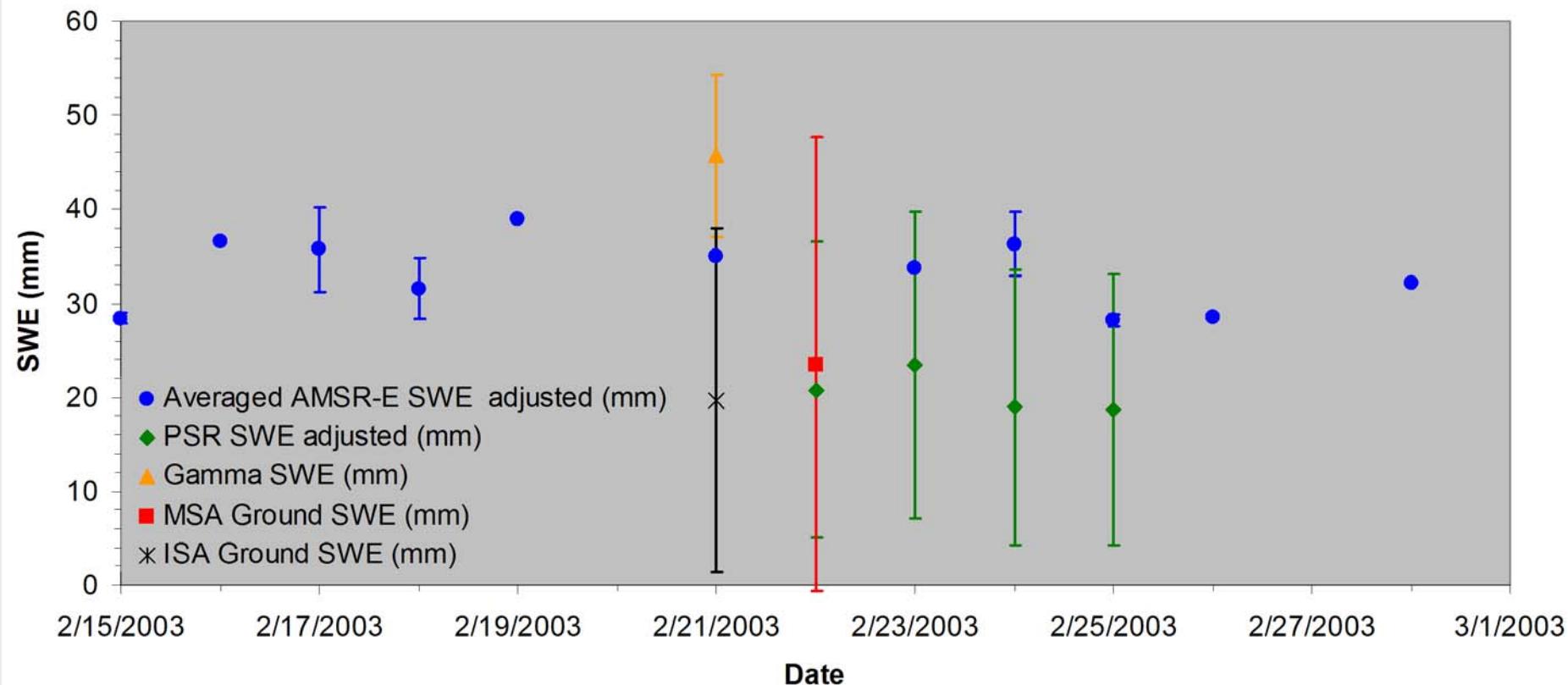


Std_{Diff} = 2.103



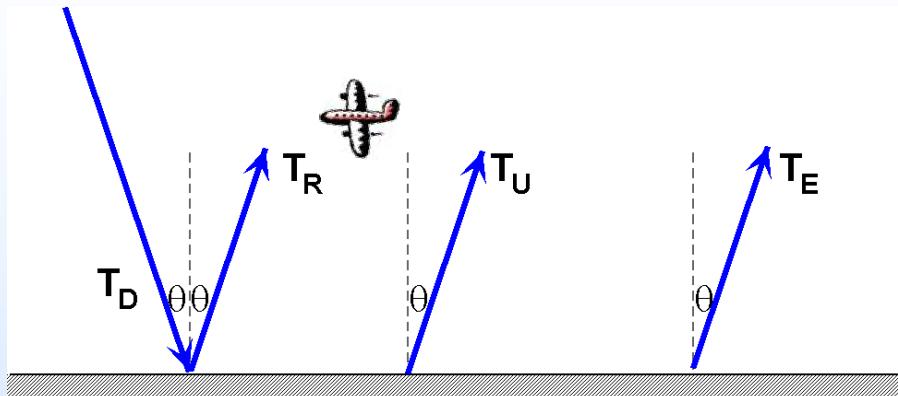
Radiometric SWE Algorithm

- Coefficient $a = 4.8$ is inversely related to grain radius. For North Park the measured grain radii were 0.7 mm and 0.5 mm for ISA and MSAs respectively (average 0.6). For a grain radius of 0.6 mm, $a = 1.2 \text{ mm K}^{-1}$.



Adjusted PSR is probably the best representation of SWE quantity since it consists of complete MSA coverage & has best agreement with ground data.

RT Calculation of Surface Emissivity



$$T_B = T_R + T_U + T_E$$

T_B = brightness temperature at aircraft observation level

$T_R = T_D (1 - \epsilon_s) e^{-\tau \sec \theta}$ (due to reflection at the surface)

T_D (due to downwelling at the surface)

T_U (due to upwelling)

$T_E = \epsilon_s T_s e^{-\tau \sec \theta}$ (due to surface emission)

T_s = surface temperature

$$\tau = \int_0^H \alpha(z) dz \quad (\text{optical depth from surface to observation level})$$

RT Calculation of Surface Emissivity

ε_S = surface emissivity

$$T_B = T_D (1 - \varepsilon_S) e^{-\tau \sec \theta} + T_U + \varepsilon_S T_S e^{-\tau \sec \theta}$$

Solving for surface emissivity gives :

$$\varepsilon_S = \frac{(T_B - T_U) e^{\tau \sec \theta} - T_D}{(T_S - T_D)}$$

PSR

MRT*

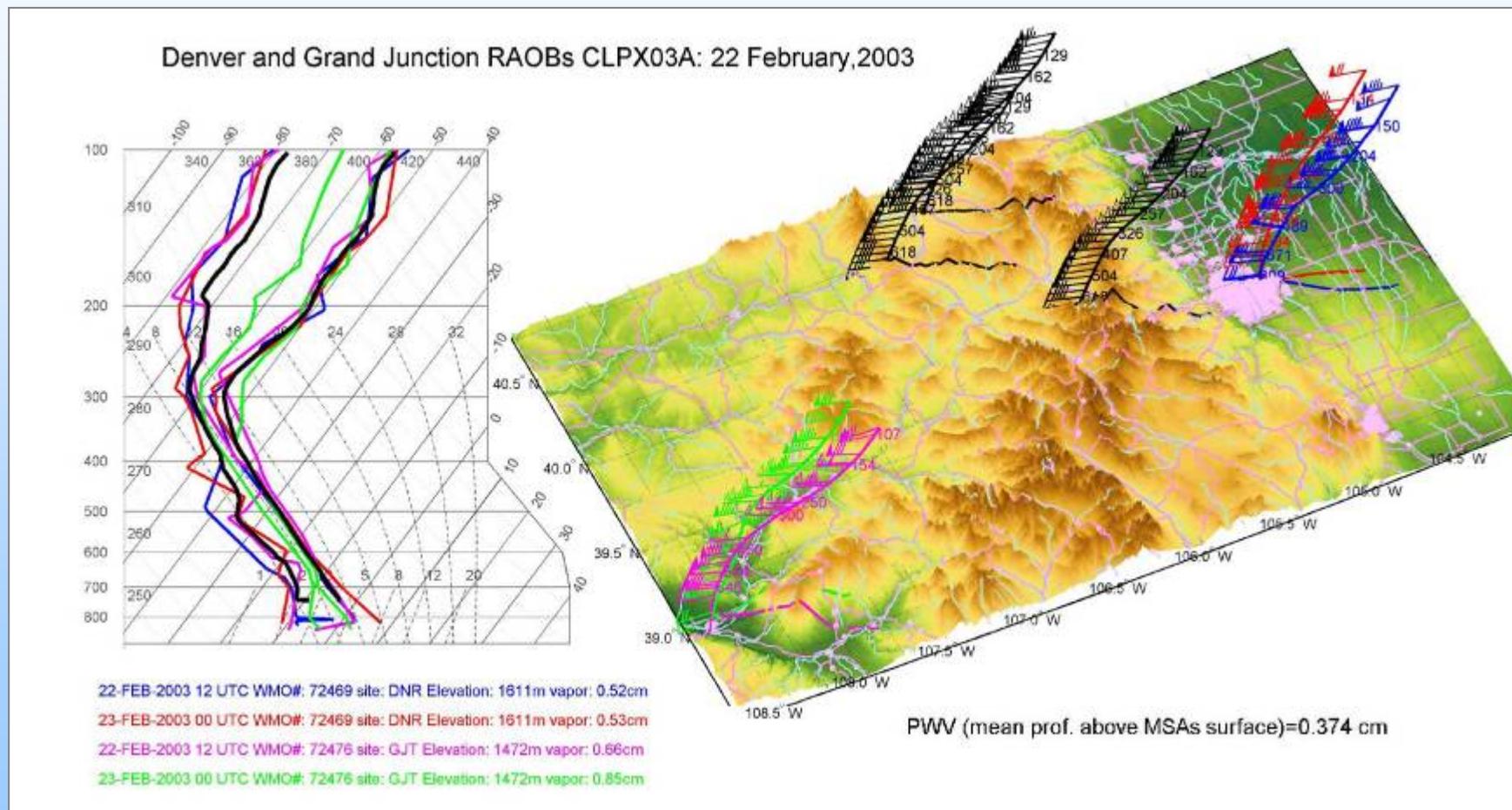
FSL LAPS

10 km surface resolution

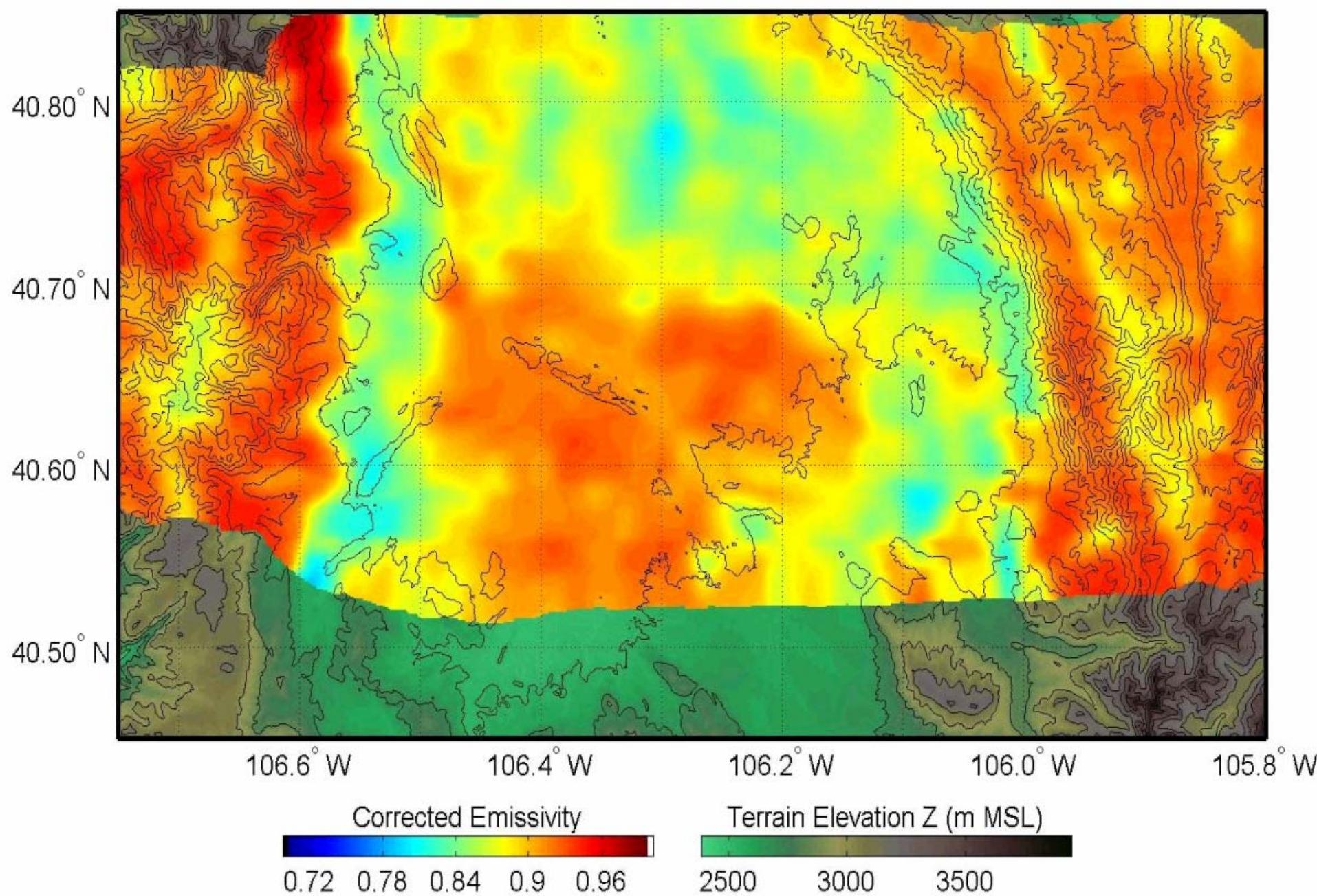
* MRT using NWS raobs augmented by surface observations from NCAR flux tower (Mahrt et al.)

Profile Data for Emissivity Calculation

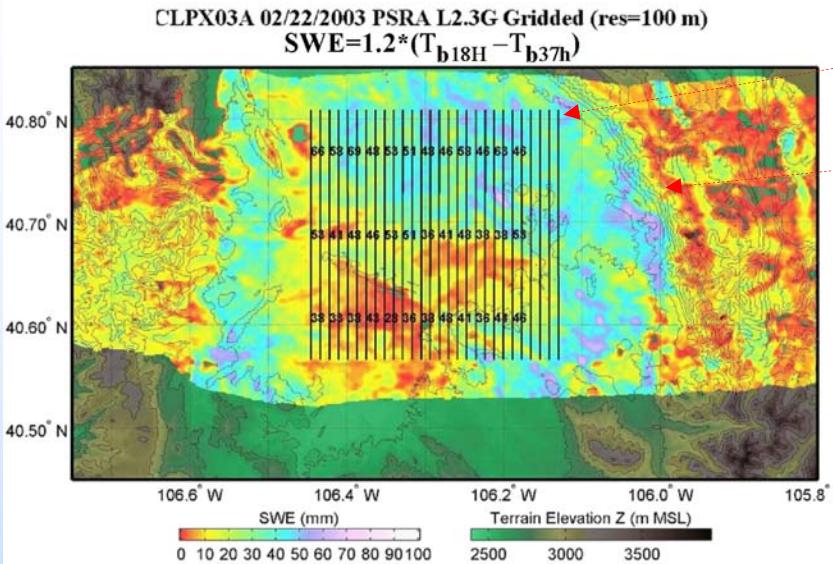
- Atmospheric soundings used in RT calculation are a composite of Grand Junction and Denver RAOBs.



North Park CLPX03A 02/22/2003 PSRA L2.3G Gridded (res=100 m) Corrected Emissivity 18.7 GHz H-POL



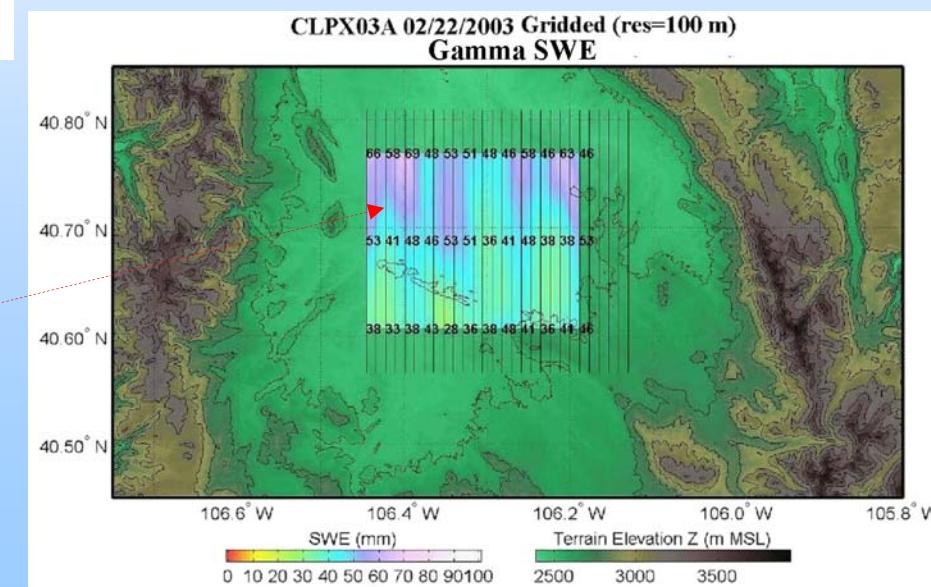
North Park PSR/GAMMA SWE Comparison



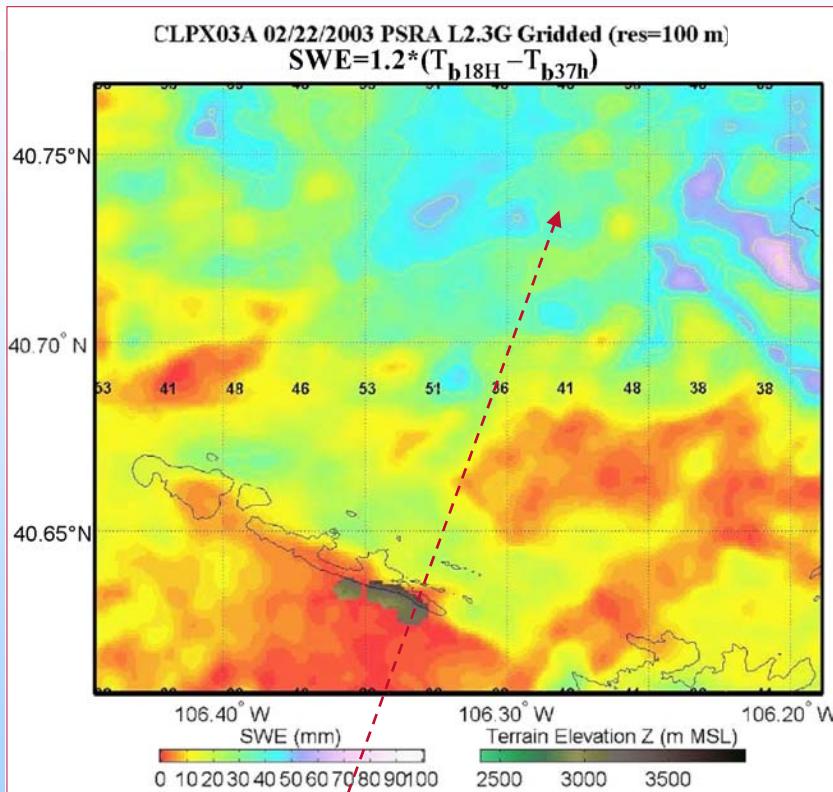
GAMMA observation lines

PSR= $1.2 * (T_{b18H} - T_{b37H})$ Image

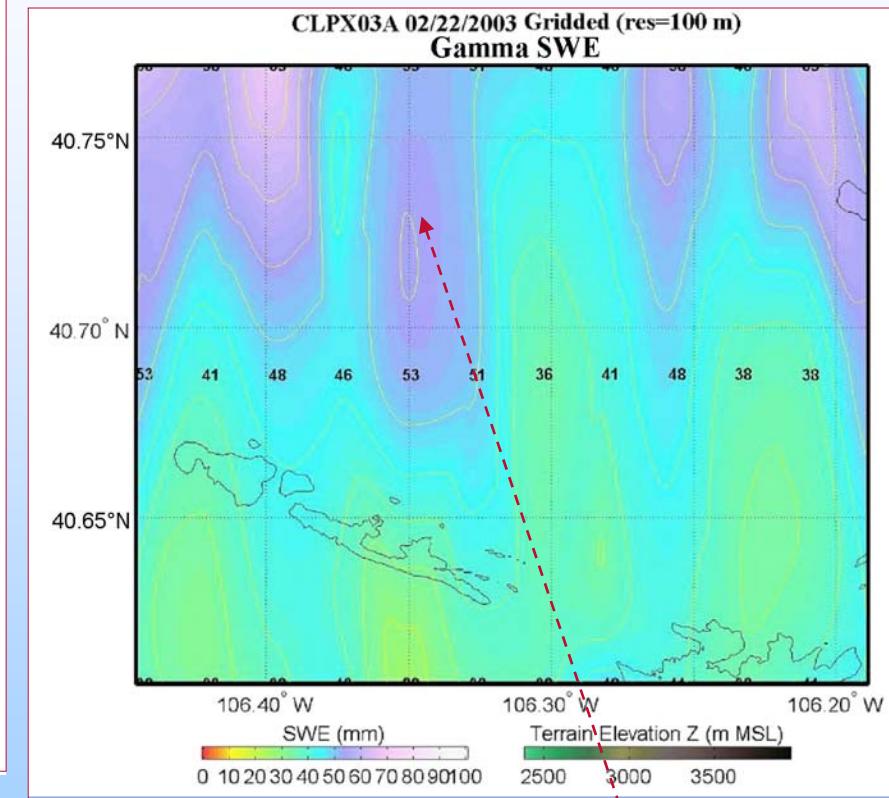
GAMMA SWE gridded image



North Park PSR/GAMMA SWE Comparison

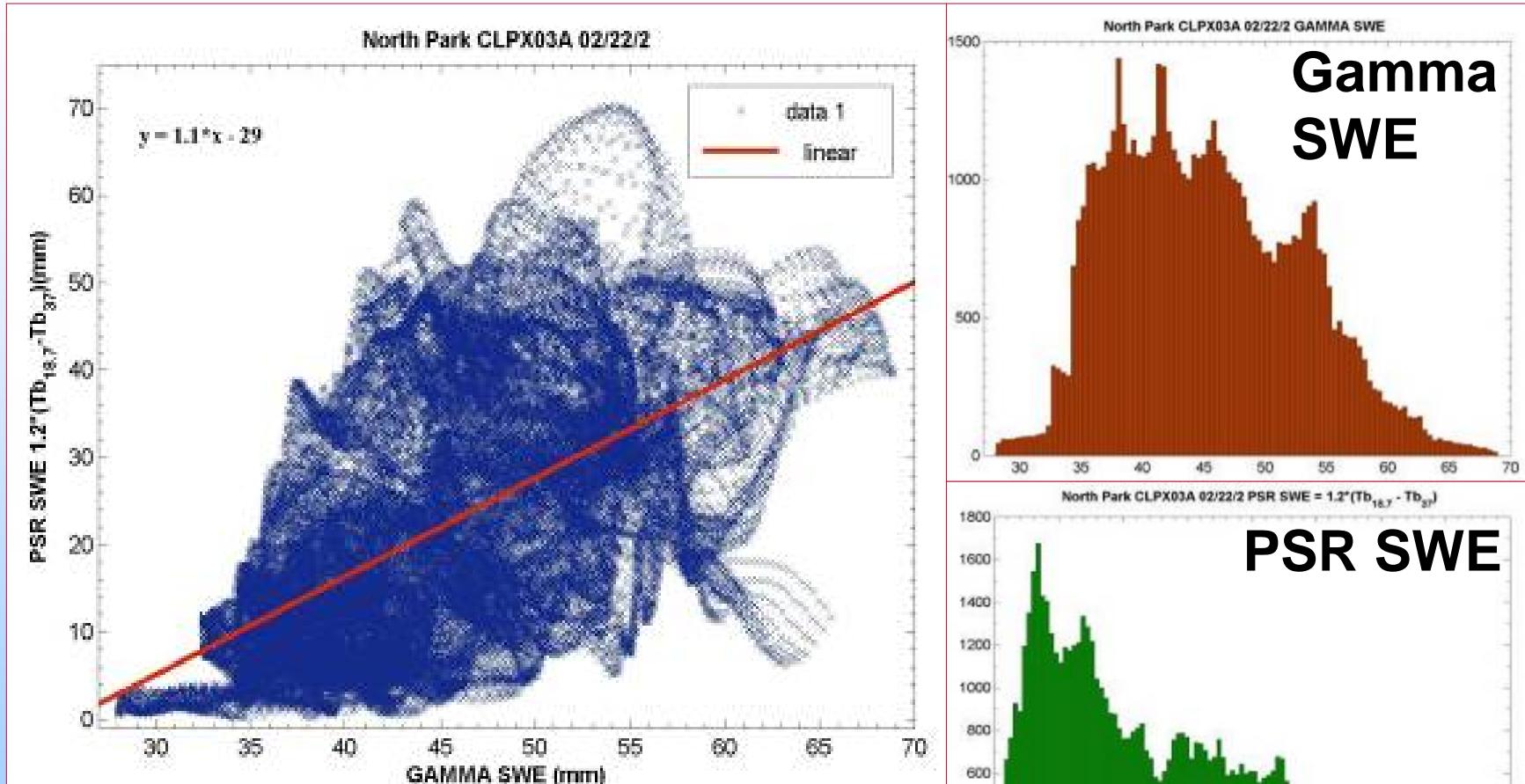


PSR Image [=1.2*($T_{b18.7}$ - T_{b37})]



GAMMA SWE gridded image

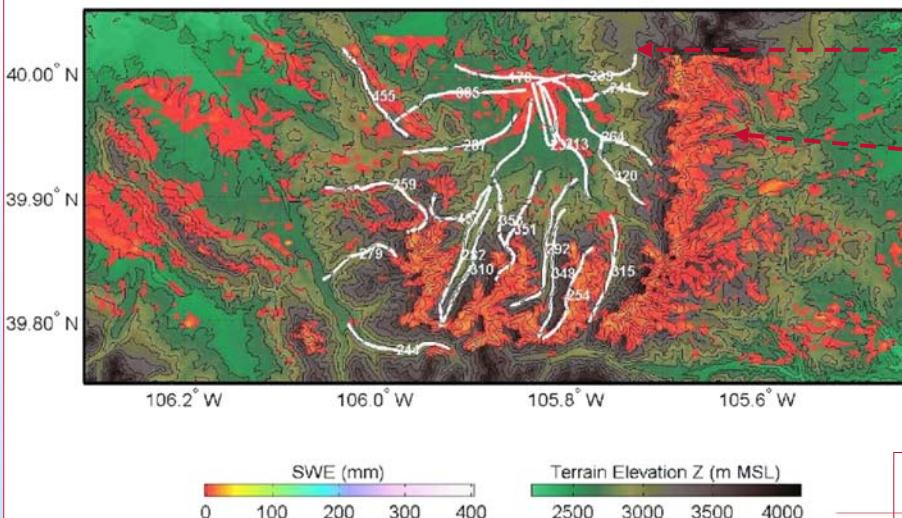
North Park PSR-GAMMA SWE Comparison



$$y = 1.1x - 29$$

Fraser PSR-GAMMA SWE Comparison

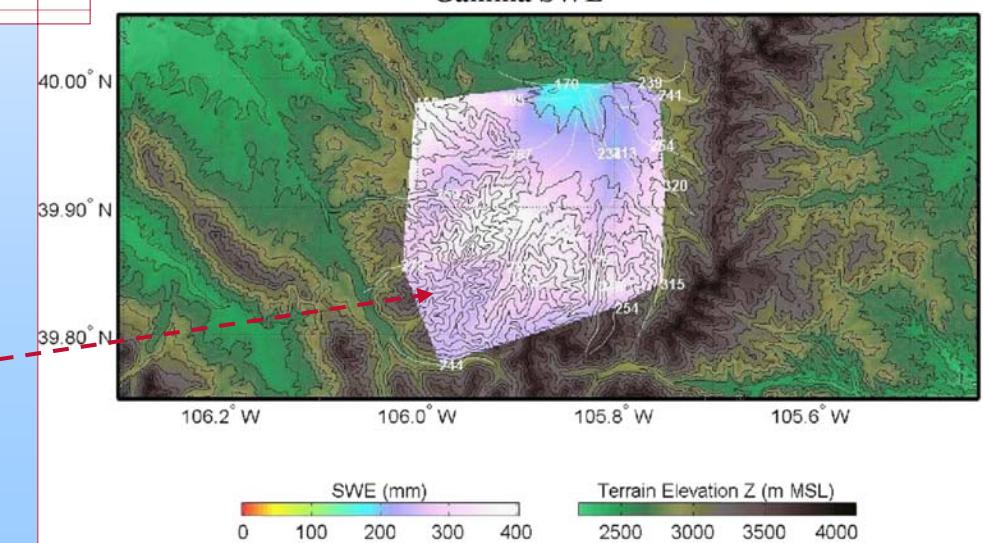
CLPX03B 03/25/2003 PSRA L2.3G Gridded (res=100 m)
 $SWE = 1.2 * (T_{b18H} - T_{b37h})$



GAMMA observation lines

PSR= $1.2 * (T_{b18.7} - T_{b37})$ Image

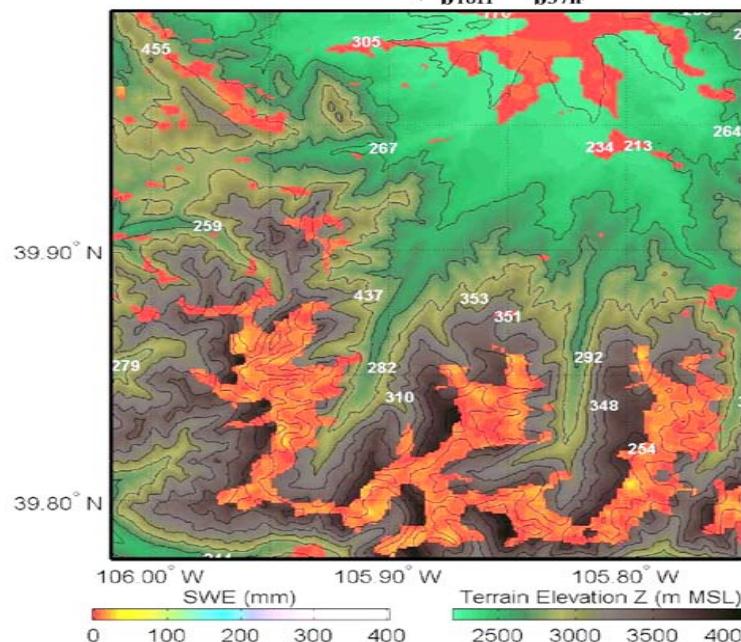
CLPX03B 03/25/2003 Gridded (res=100 m)
Gamma SWE



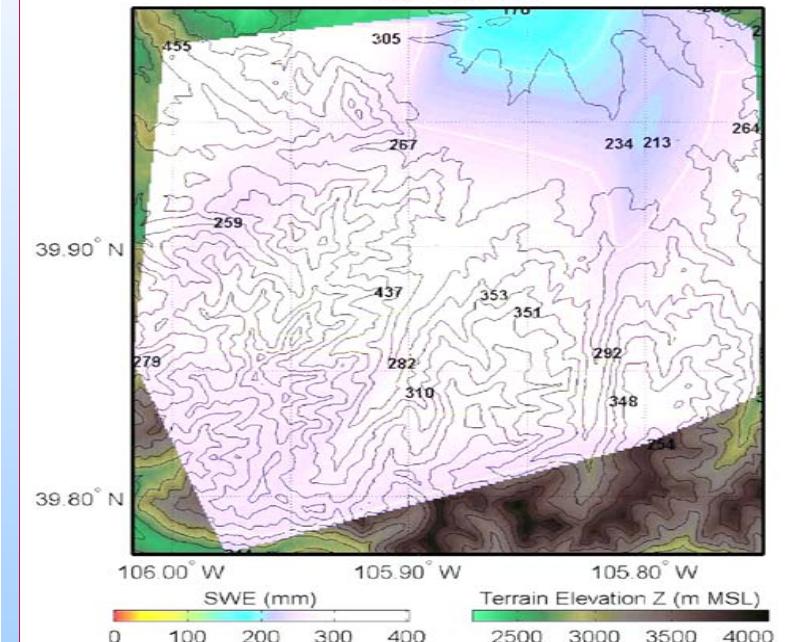
GAMMA SWE gridded image

Fraser PSR/GAMMA SWE Comparison

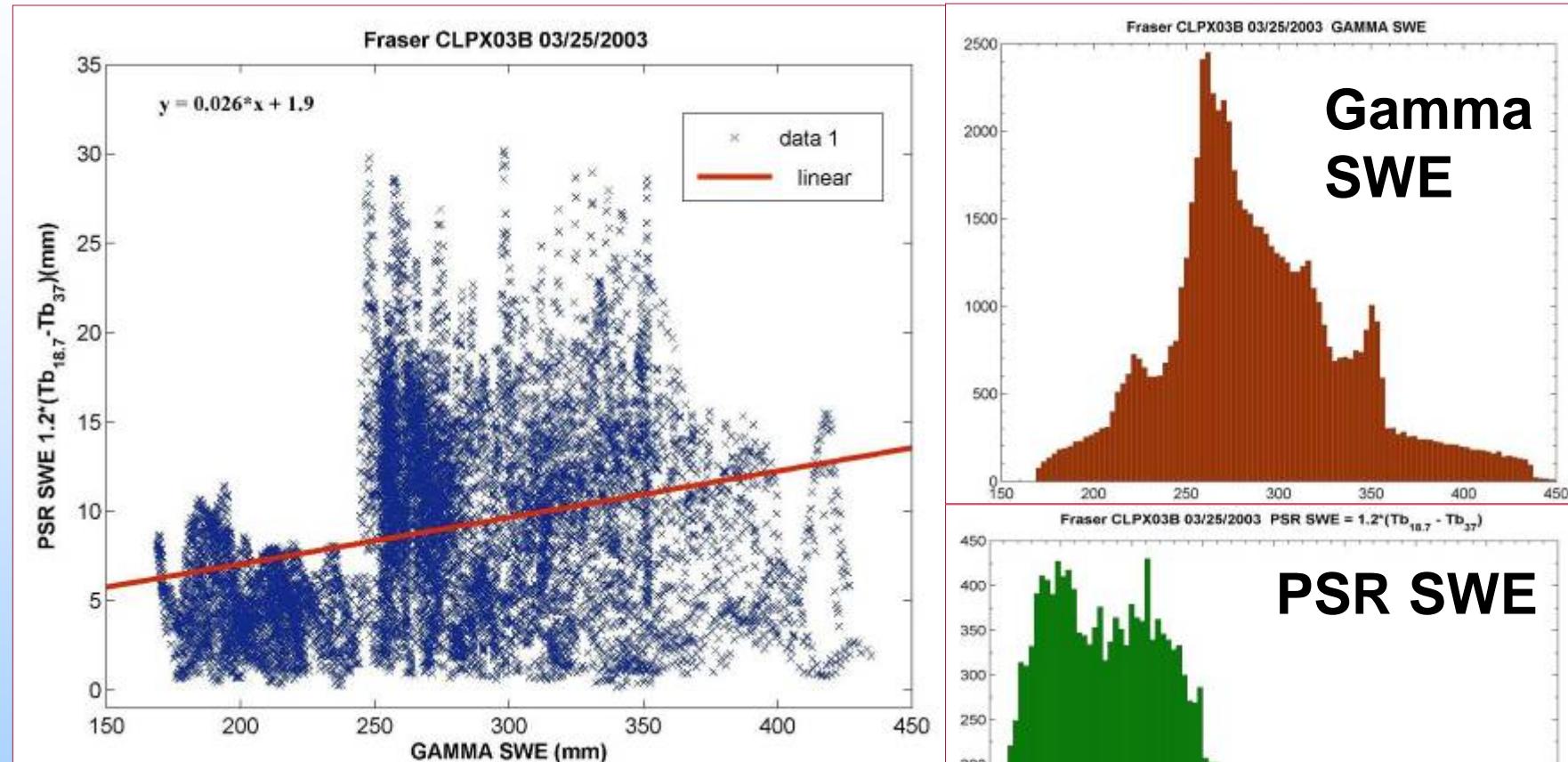
CLPX03B 03/25/2003 PSRA L2.3G Gridded (res=100 m)
SWE=1.2*($T_{b18H} - T_{b37h}$)



CLPX03B 03/25/2003 Gridded (res=100 m)
Gamma SWE



Fraser PSR/GAMMA SWE Comparison



$$y = 0.026 x + 1.9$$

Summary - CLPX

- A method to obtain facet-normalized 100-m airborne passive microwave surface emissivity maps has been demonstrated.
- The first high-resolution passive microwave and gamma SWE intercomparisons show some (albeit poor) spatial correlations in all three CLPX MSA cases, with the best being the North Park case where the terrain is least rugged and snowpack was shallow.
- One possible cause of the PSR-Gamma discrepancies is Gamma sensitivity to ground meltwater. Gamma SWE amounts tend to “collect” downhill within a basin during melt. The radiometric SWE algorithm tends to reject ground meltwater. PSR/CX concurrent measurements of soil moisture will provide additional information.
- PSR/A and PSR/CX measurements compare favorably.

SMEX04 / NAME

SMEX: A Series of Intensive Field Campaigns Incorporating Diverse Land Covers and Climates

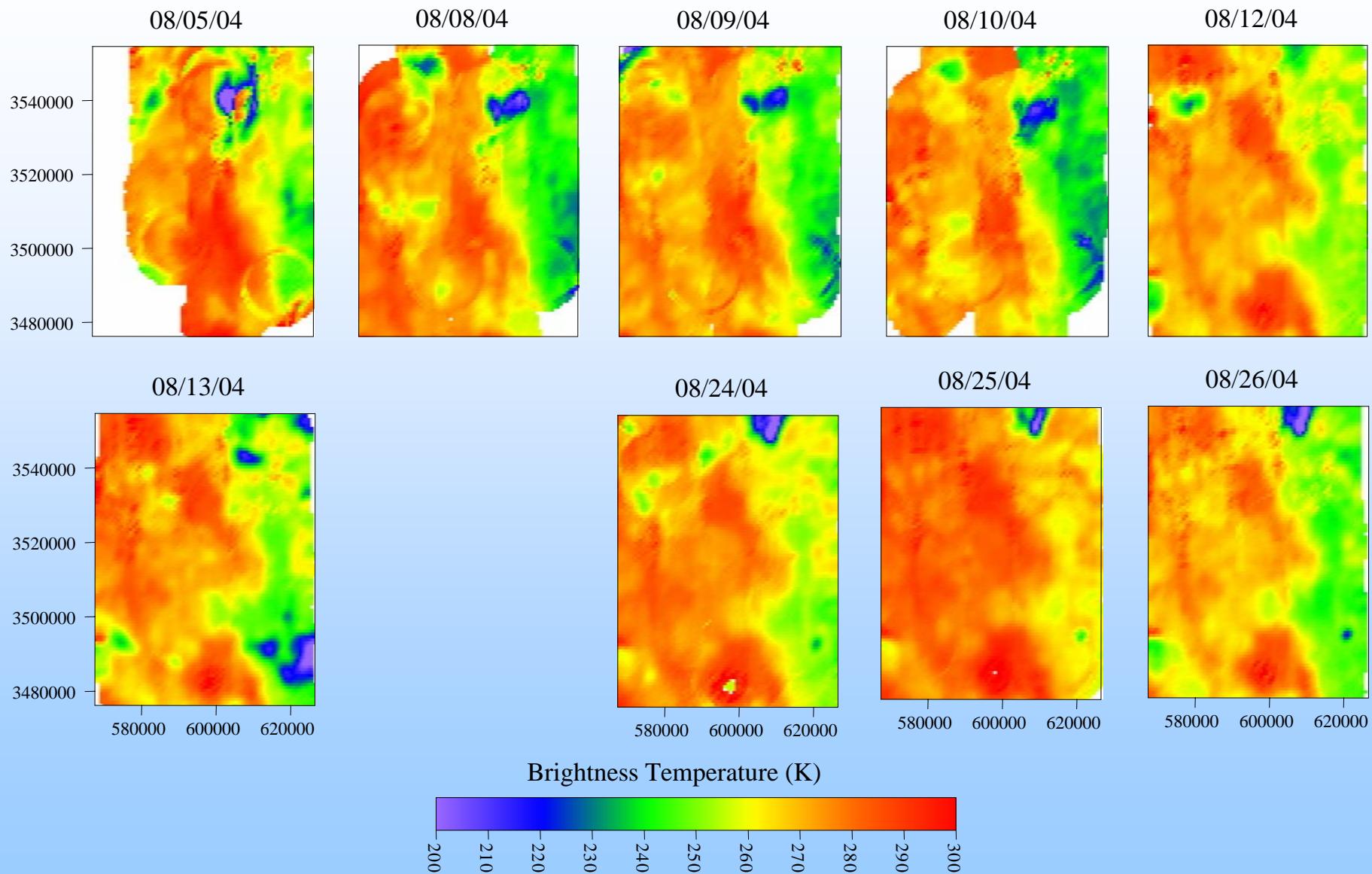


SMEX04 Elements

- Two regional study sites, Arizona and Sonora provide diverse vegetation and topographic variations
- Insitu networks in each region provide long term soil moisture
- Field campaign August 2-August 27, 2004 with intensive ground sampling concurrent with aircraft and Aqua AMSR-E
- Aircraft mapping
- Satellite retrievals

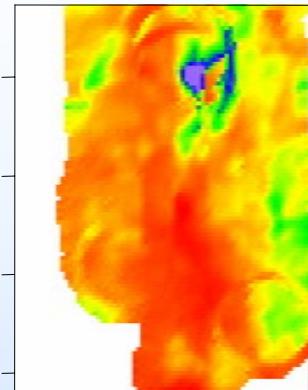
- **84 high altitude flightlines resulting in 21 mapping domains (10 – AZ and 11 - SO)**
- **RFI analysis: best channels 7.32 GHz and 10.7 GHz**
- **RFI removal**
- **Temporal normalization of multiple flightlines**
- **800 m grid mapping (high altitude nominal beam position spacing is 300 m)**

SMEX04 PSR 7.32H (Arizona)

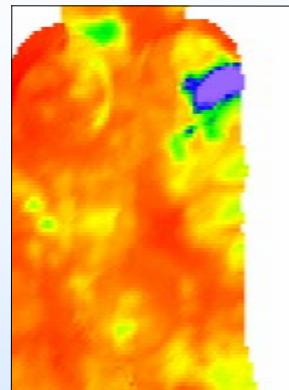


SMEX04 PSR 10.7H (Arizona)

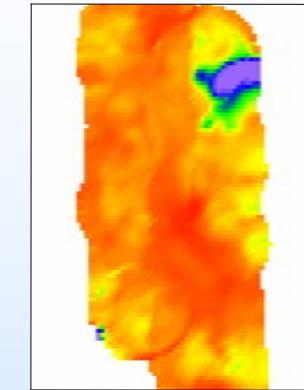
08/05/04



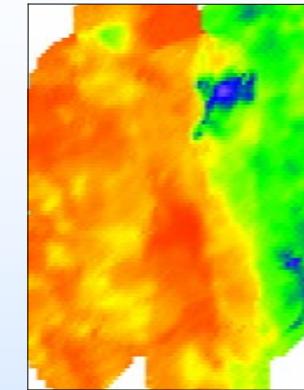
08/08/04



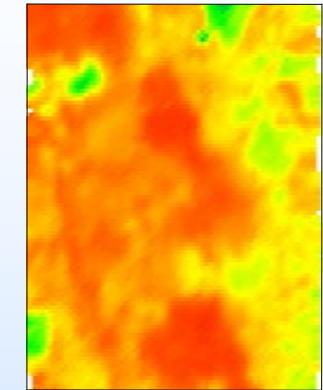
08/09/04



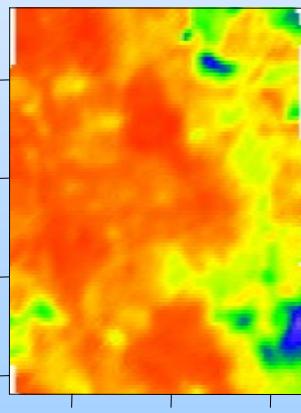
08/10/04



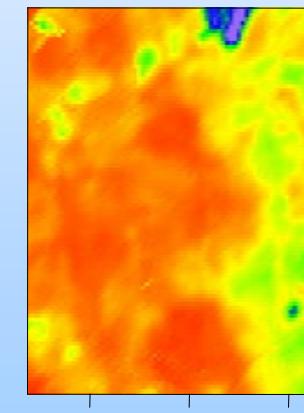
08/12/04



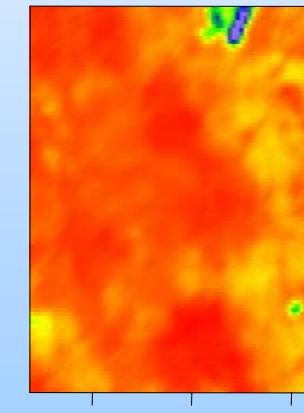
08/13/04



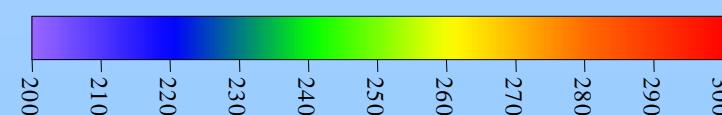
08/24/04



08/25/04



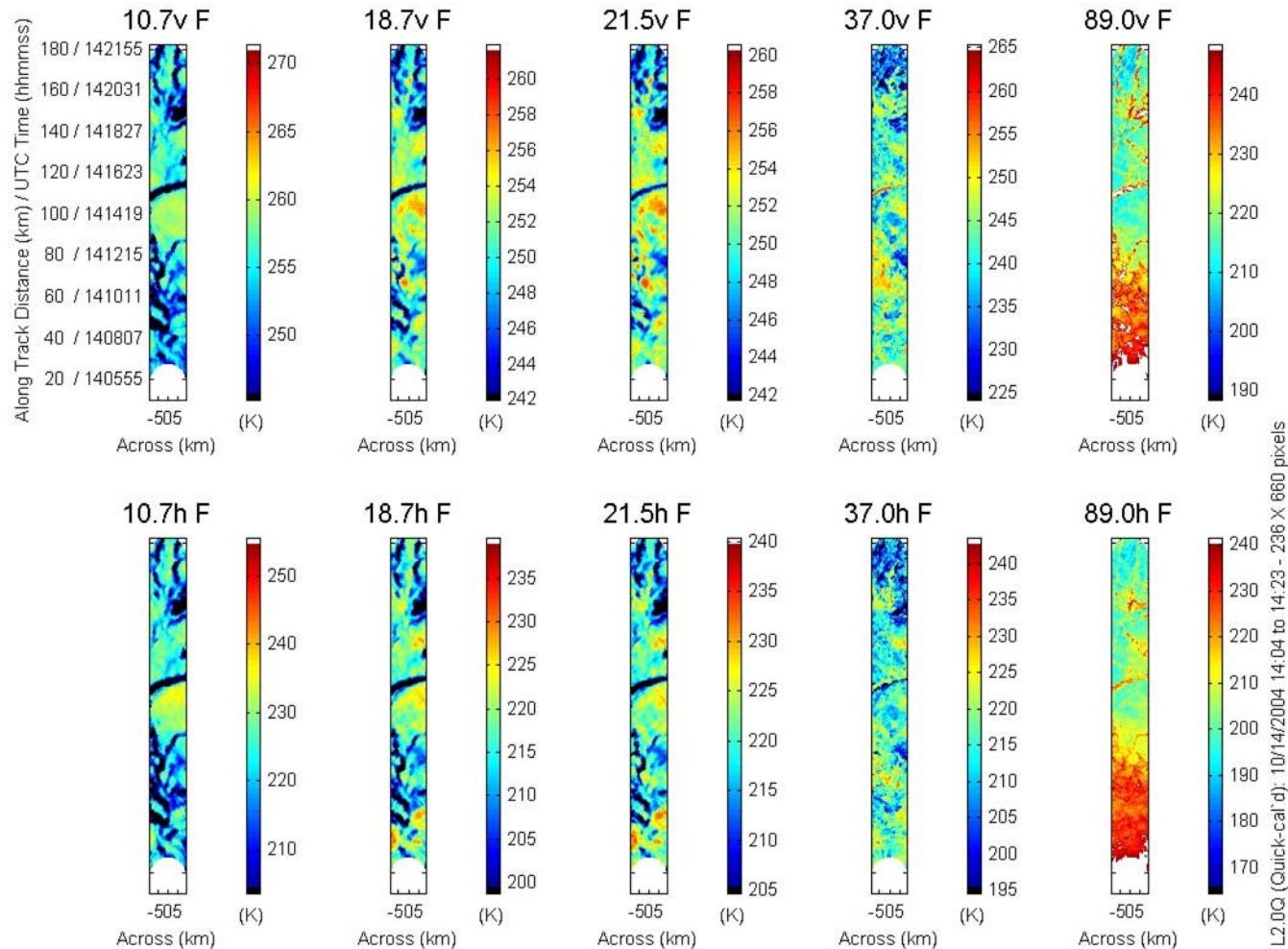
Brightness Temperature (K)



AMSR-E Antarctic Sea Ice 2004

AASI04

NOAA PSR/A AASI04 Imagery - NRL P-3A



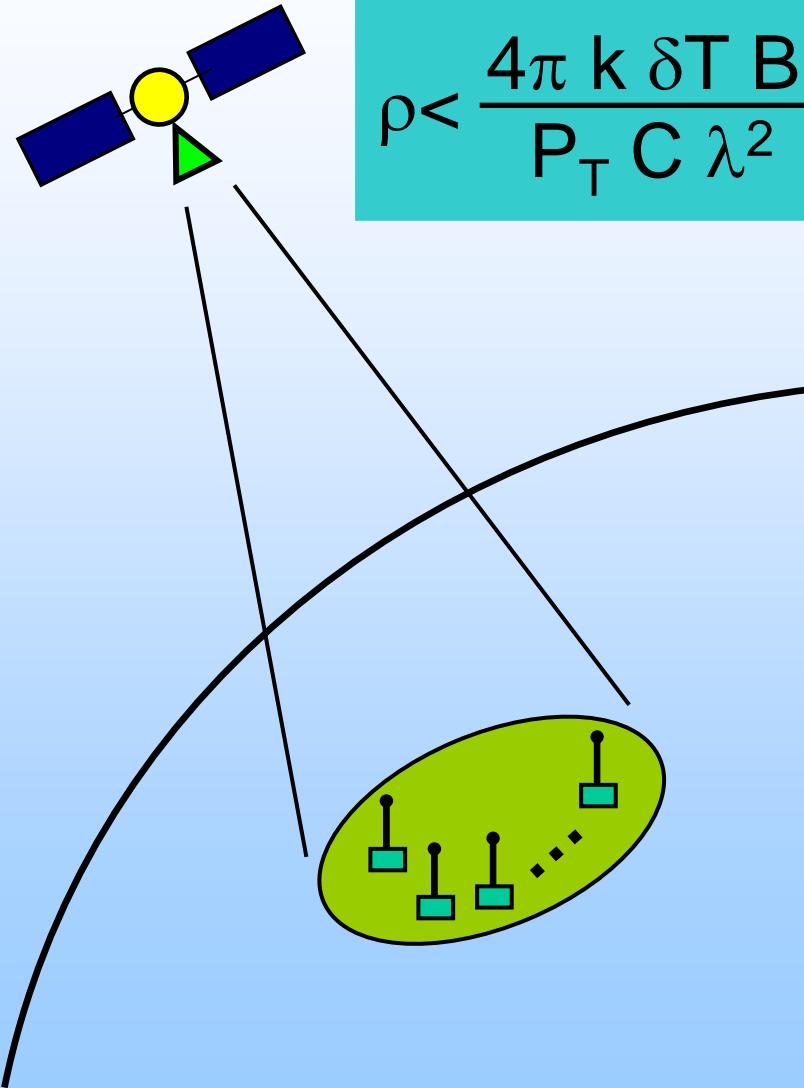
An Interference Mitigation Technique for Passive Remote Sensing of Soil Moisture



- Nominal flight altitude 55,000' (~17 km)
- PSR scan period 40 sec
- Sweep period 800 msec
- ~3-db pixel sampling at all 22 spectrometer sub-bands
- Previous 4-sub-band radiometer operated in parallel with spectrometer



RF Interference to C-Band Passive Microwave Radiometers



$$\rho < \frac{4\pi k \delta T B}{P_T C \lambda^2}$$

ρ = Density of interfering transmitters (m^{-2})
 δT = Interference threshold (K)
 B = Detection bandwidth (Hz)
 λ = Wavelength (m)
 P_T = Power transmitted per interferer (W)
 k = Boltzmann's constant (1.38E-23 J/K)
 C = Antenna coupling factor

AMSR-E Example:

$P_T = 100 \text{ mW (20 dBm)}$

$\delta T = 1 \text{ K}$

$B = 200 \text{ MHz}$

$\lambda = 4.3 \text{ cm (6.9 GHz)}$

$C = 1$ (main-main lobe coupling)

$$\rightarrow \rho < 1.9E-4 (\text{km}^{-2})$$

Or, an average transmitter separation distance of $\sim 73 \text{ km}$ is required for non-interference.

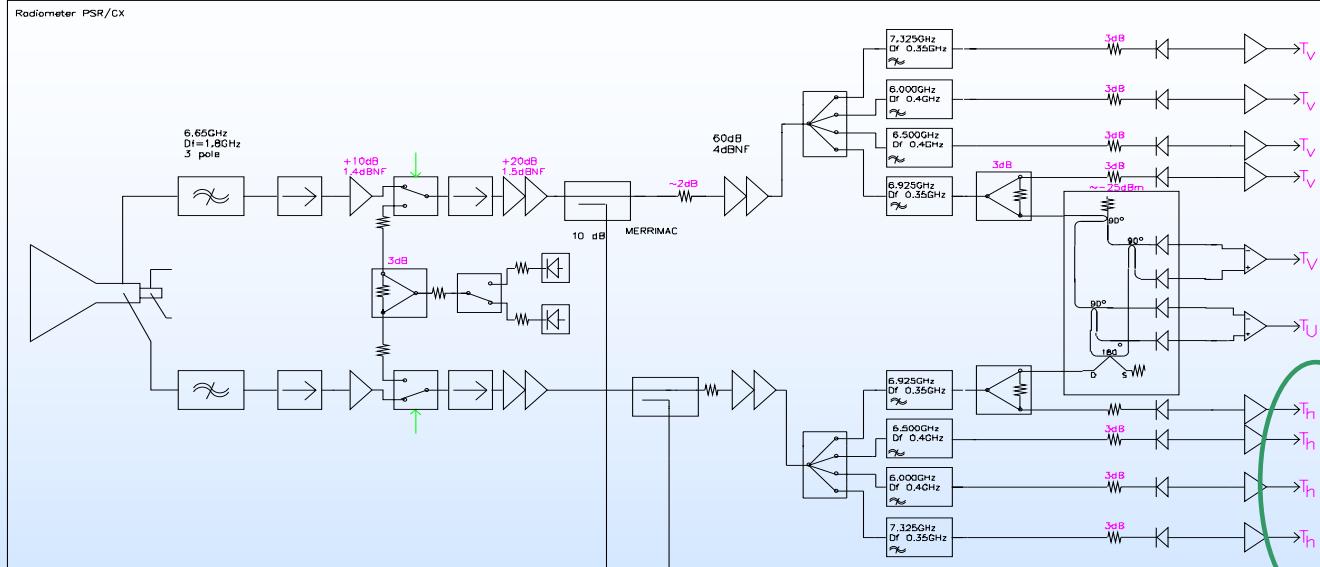
Essential Interference Mitigation Techniques

- 1) Subband diversity** – Anthropogenic interference often narrowband (~a few to hundreds of MHz) WRT radiometric bands.
- 2) Polarization diversity** – Geophysical v-h difference often predictable to within a few K, while v-h interference deviations are often larger.
- 3) Polarimetric detection** – Anthropogenic interference is often highly polarized in 3rd or 4th Stokes parameter while most natural surfaces are either predictably polarized or mostly unpolarized.
- 4) Azimuthal diversity** – Many natural surfaces are predictably isotropic whereas interference is highly isotropic (applicable to conical scanning).
- 5) Statistical moment analysis** - Anthropogenic interference is often non-Gaussian in amplitude distribution.

Spectrometer Concept

- A relatively narrow-band tunable radiometer capable of observing within either single or multiple subbands selectable over a wide frequency range could facilitate improved subband interference mitigation.
- A tunable radiometer could be used to quantify the location, power, and bandwidth of RFI.
- A tunable operational radiometer might facilitate more accurate passive Earth imaging in RFI affected bands.

PSR/CXI Spectrometer Schematic



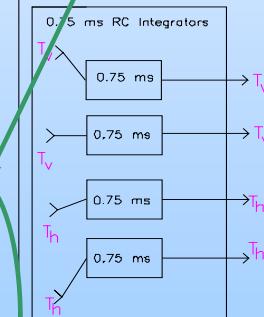
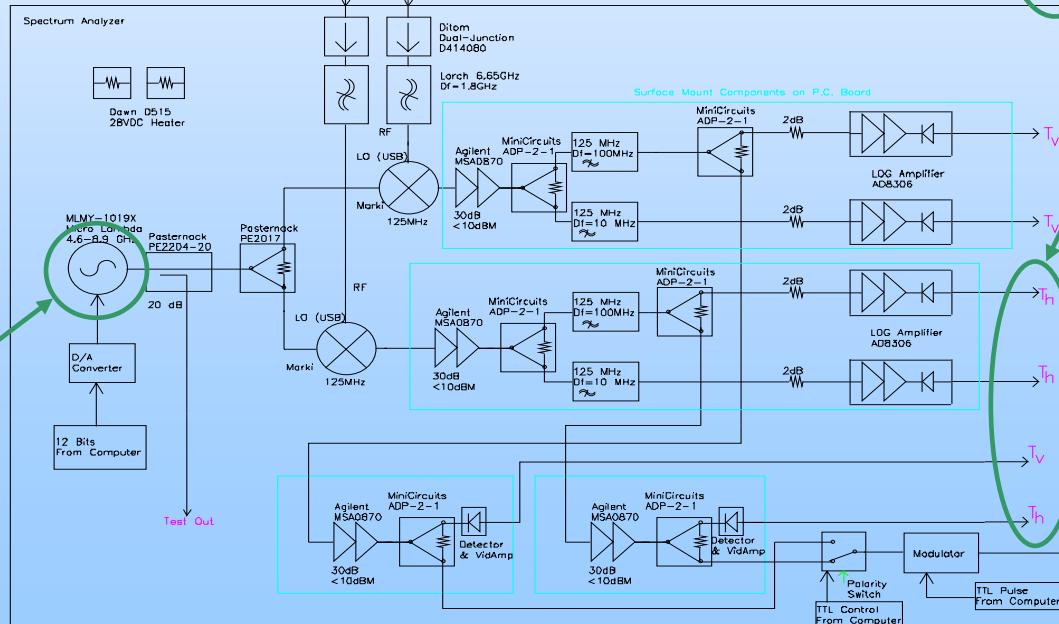
PSR/CXI
primary four
subbands

Spectrometer
logarithmic and
linear channels

Drawn By:
V. Leuskiy x6937
Last Modified:
E. McIntyre x4609
26 May 04

NOAA-ET1
etl.noaa.gov

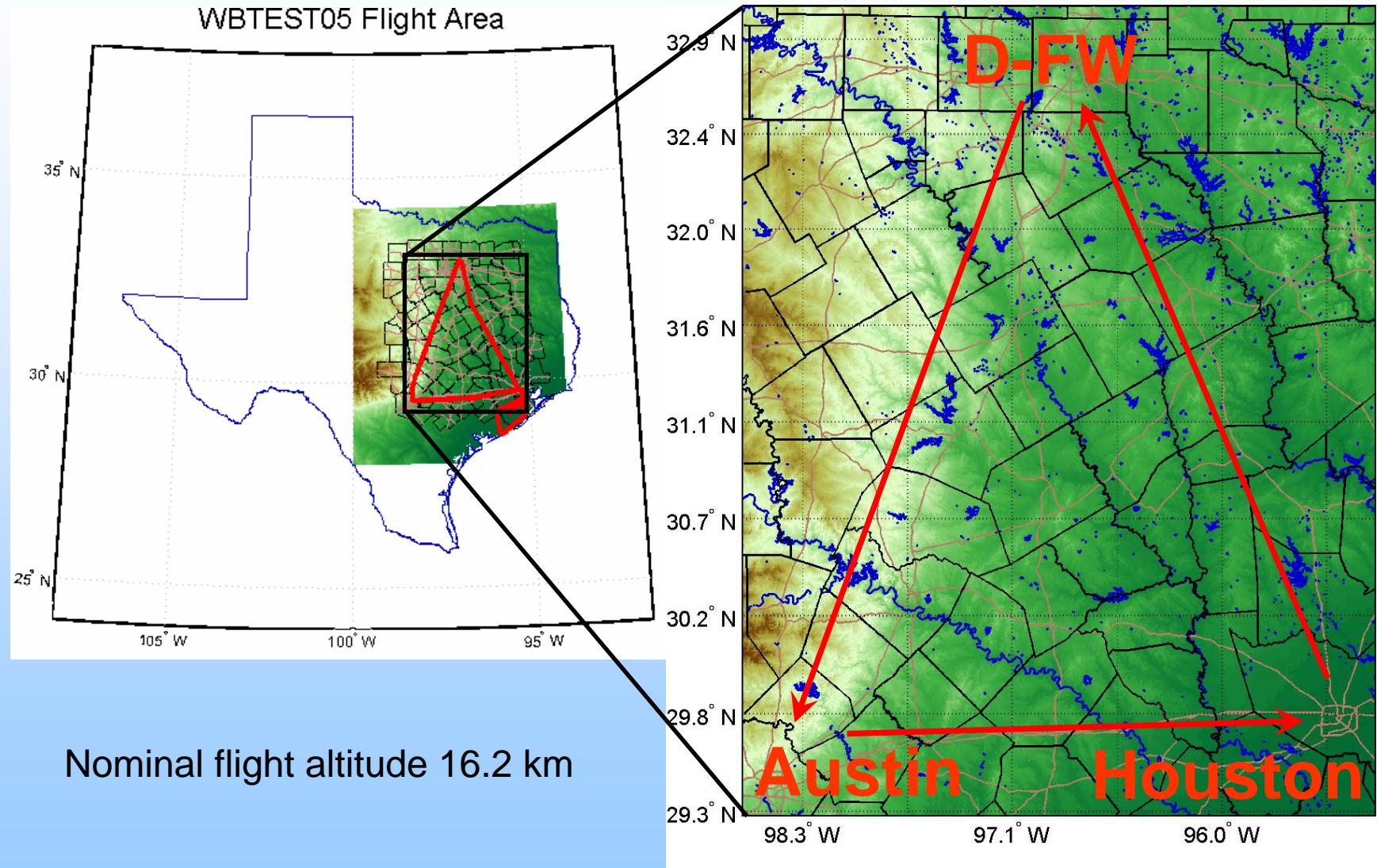
4.6 to 8.9
GHz LO



75-175 MHz BW IF
to OSU FFT system

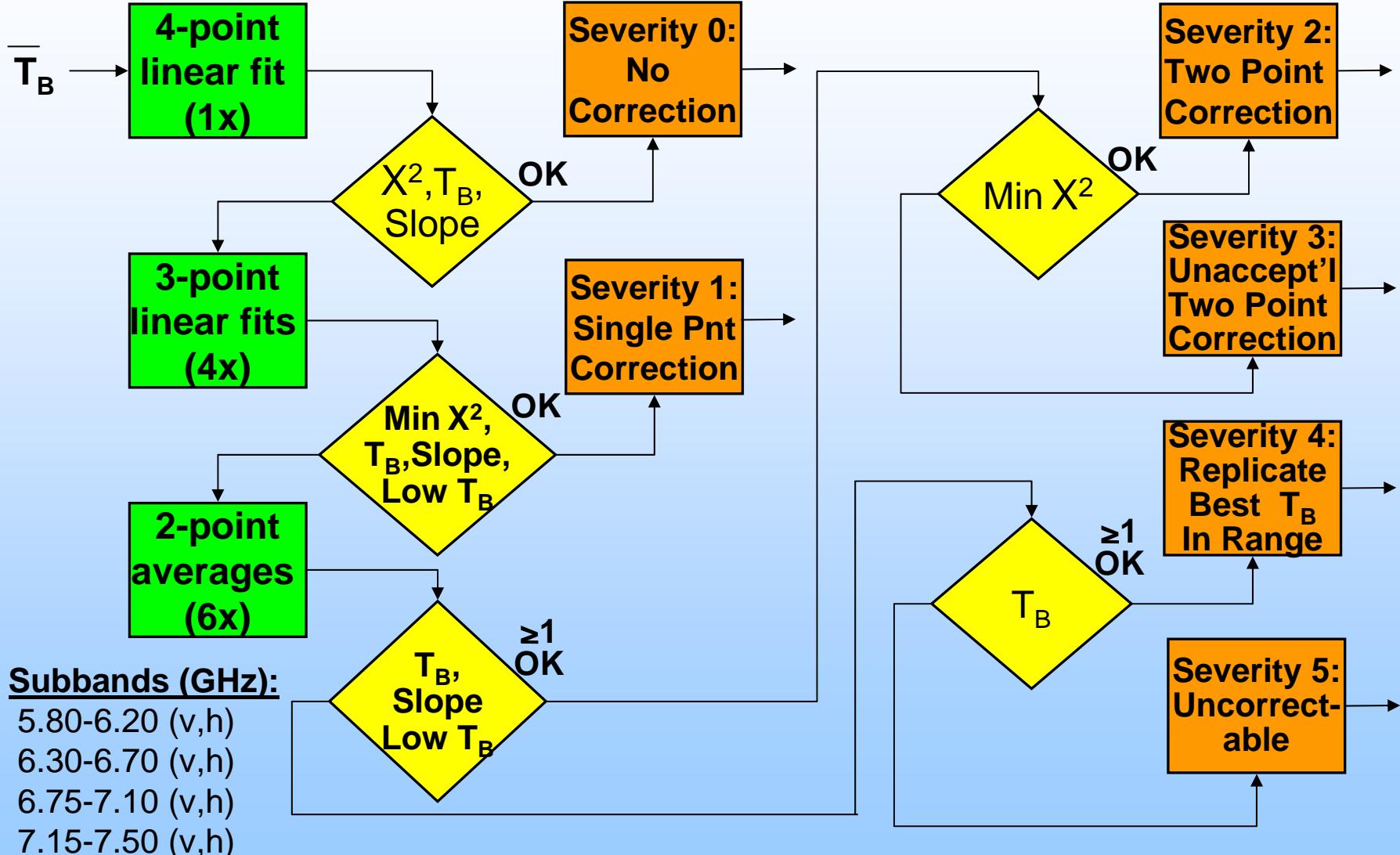
WBTEST05 Flight Area

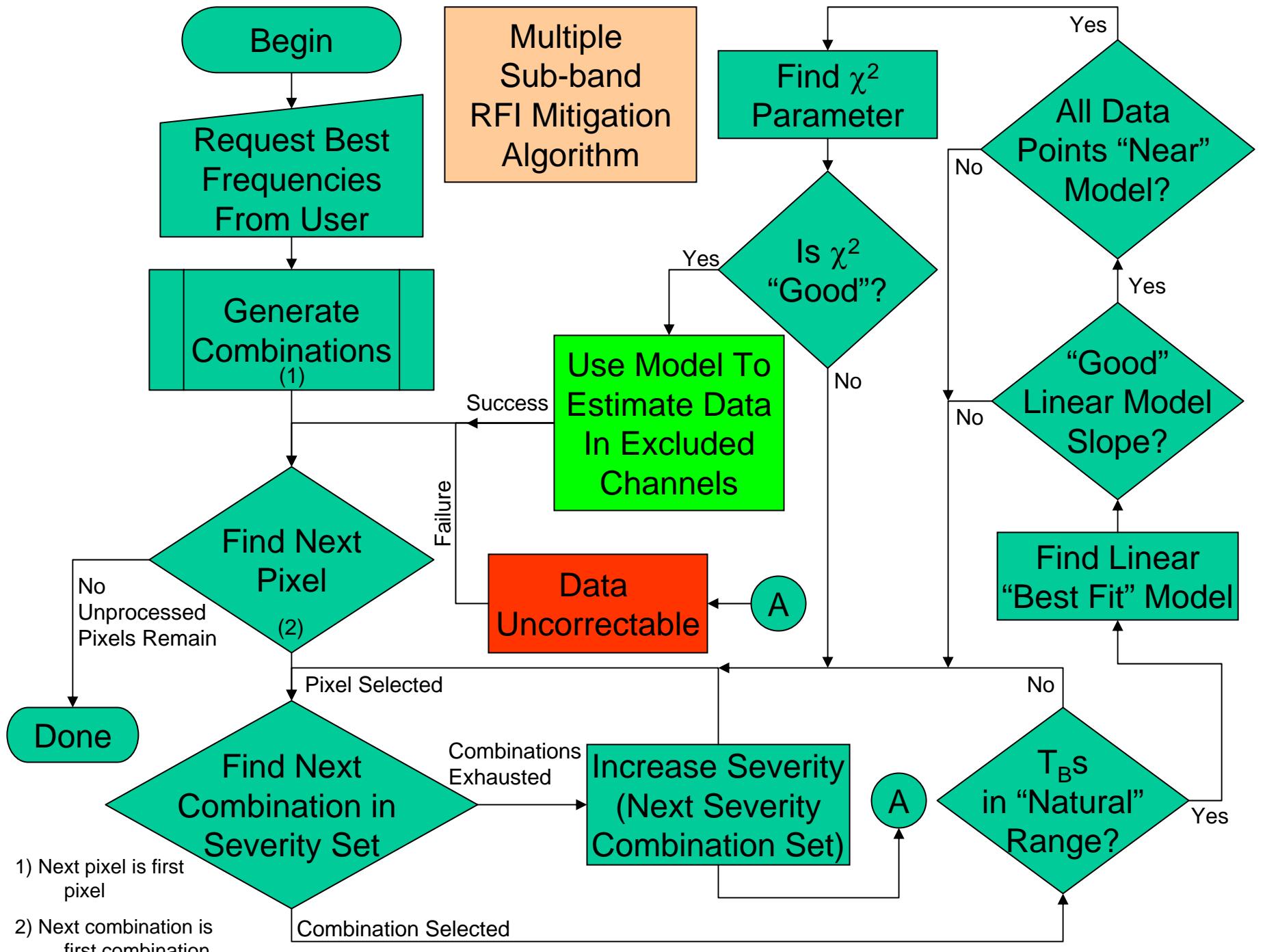
- April, August, 2005 -



Basic Spectral Algorithm

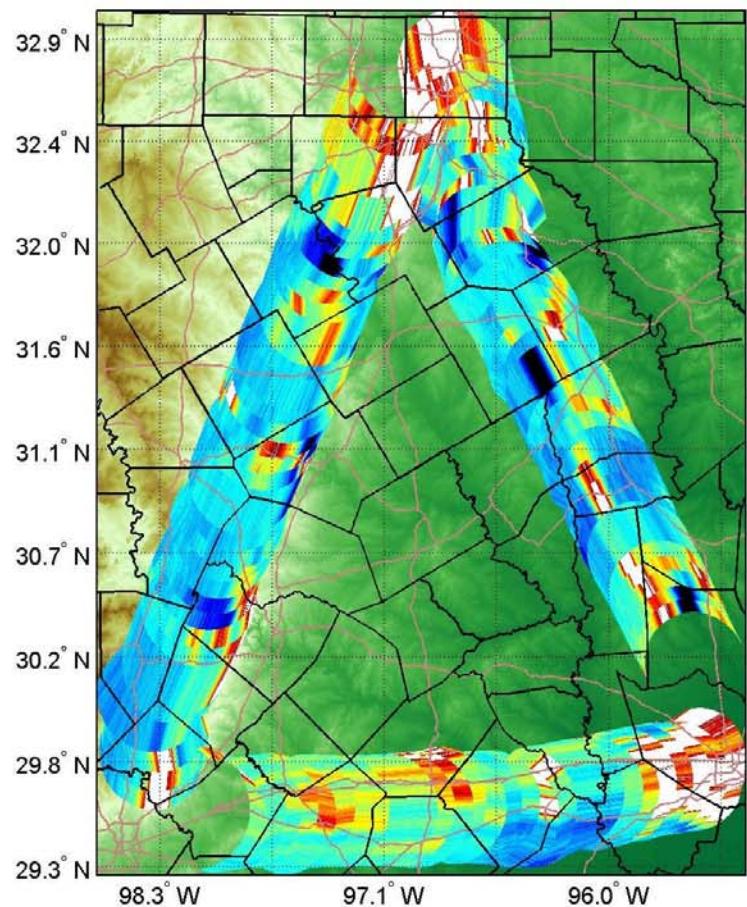
- 4 subband (PSR/CX) -



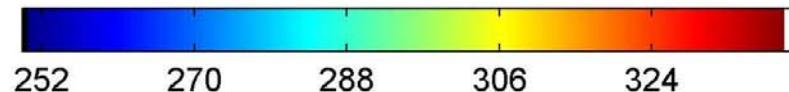
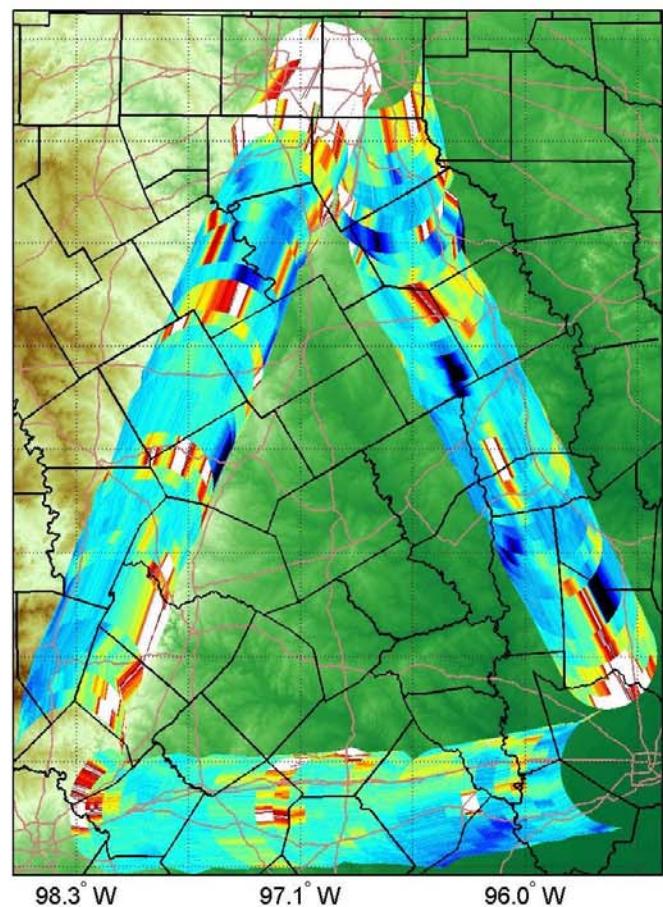


PSR/I L2.3 6.00h (B1 Ch1) April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.00h (B1 Ch1)L2.3 _{Front}

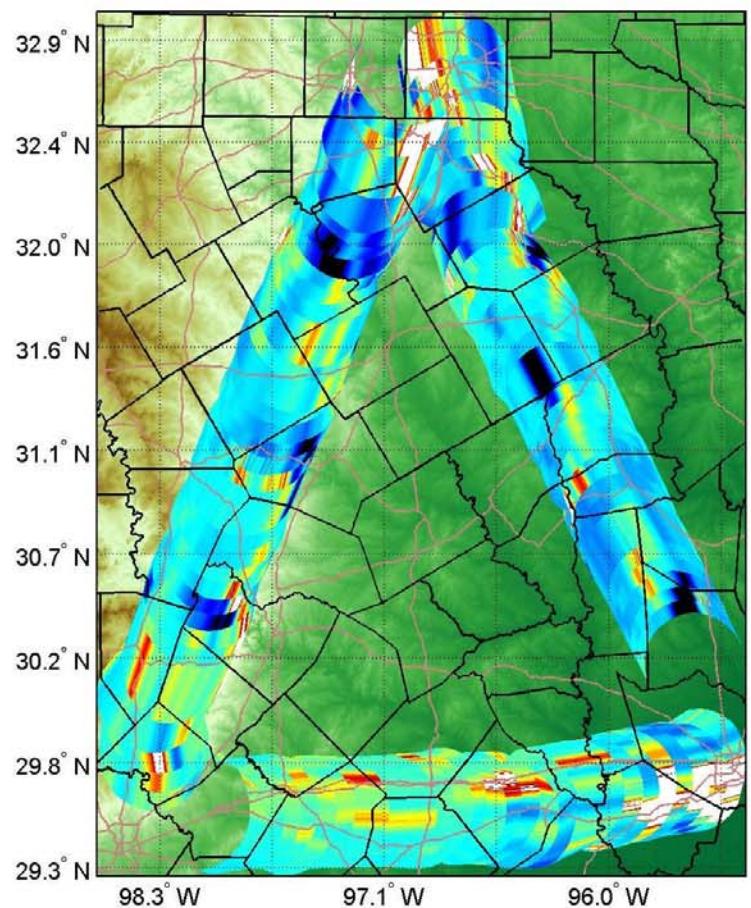


Houston, April 14, 2005: 6.00h (B1 Ch1)L2.3 _{Back}

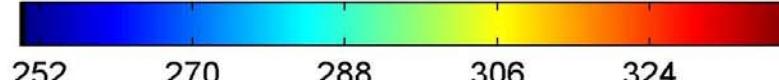


PSR/I L2.3 6.50h (B1 Ch3) April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

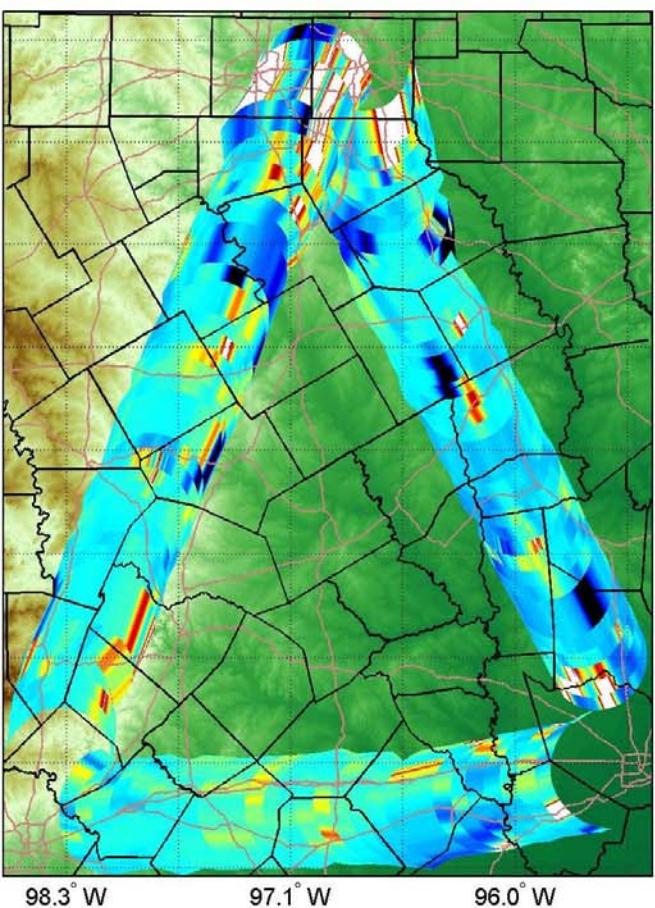
Houston, April 14, 2005: 6.50h (B1 Ch3)L2.3 _{Front}



575
460
345
230
115
Terrain Height (meters)

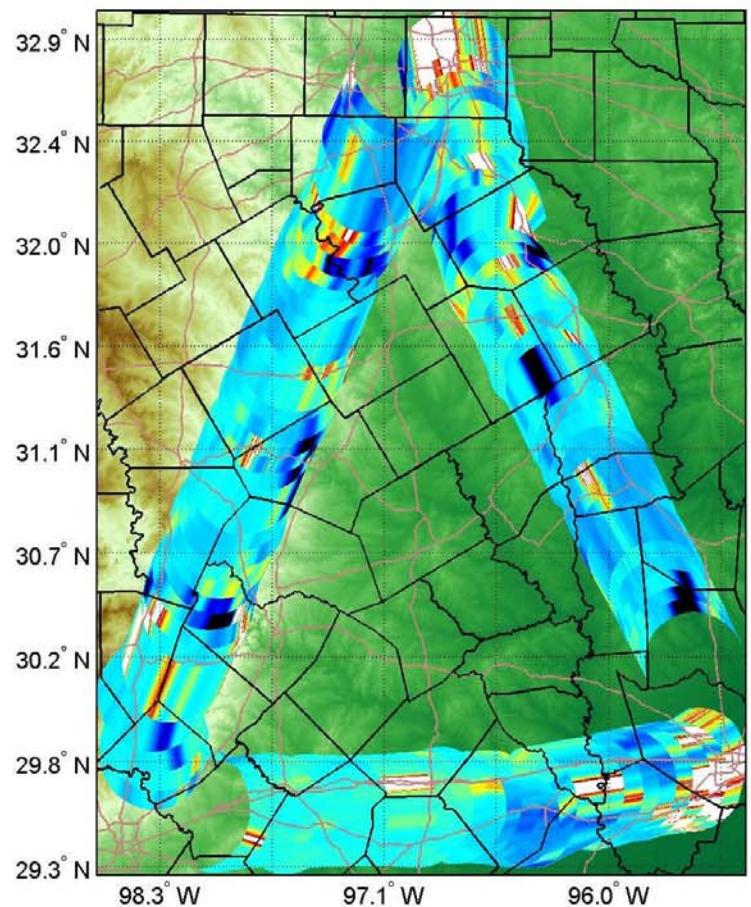


Houston, April 14, 2005: 6.50h (B1 Ch3)L2.3 _{Back}

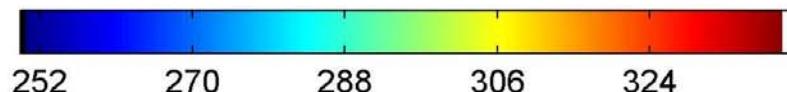
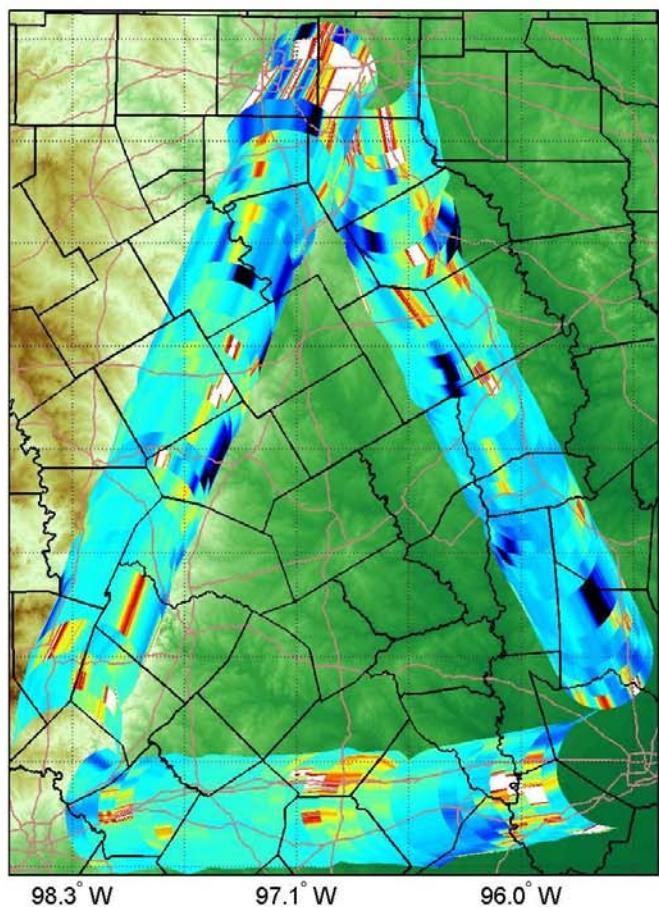


PSR/I L2.3 6.92h (B1 Ch5) April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.92h (B1 Ch5)L2.3 _{Front}

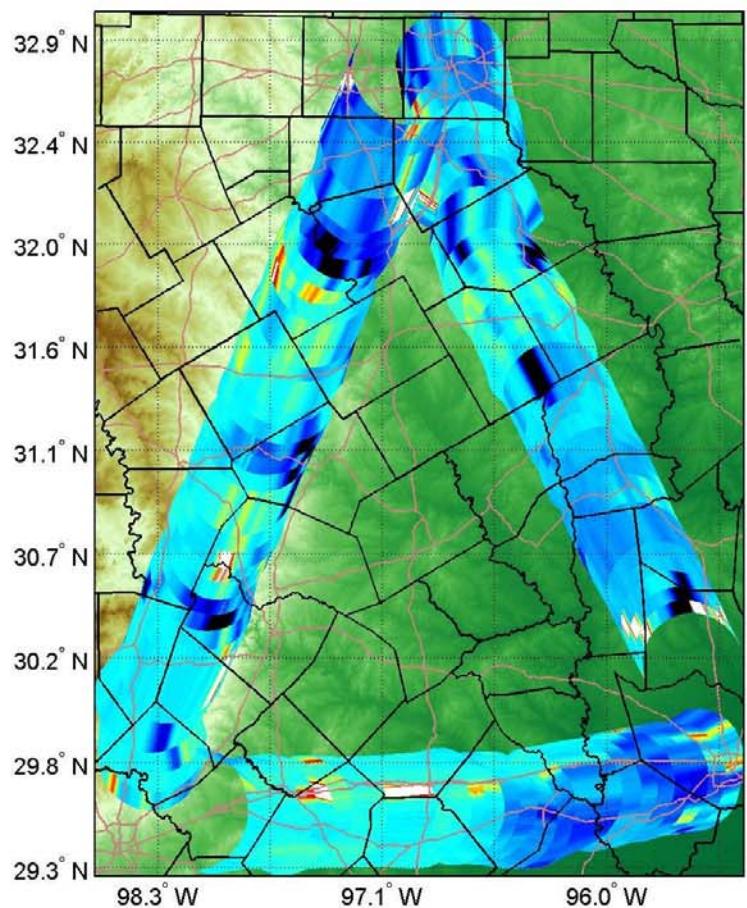


Houston, April 14, 2005: 6.92h (B1 Ch5)L2.3 _{Back}

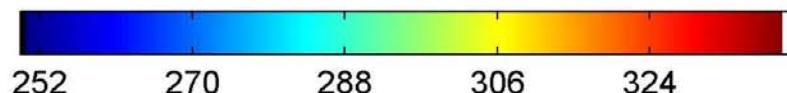
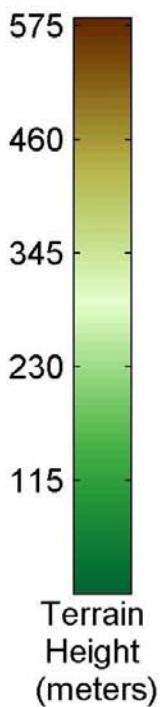
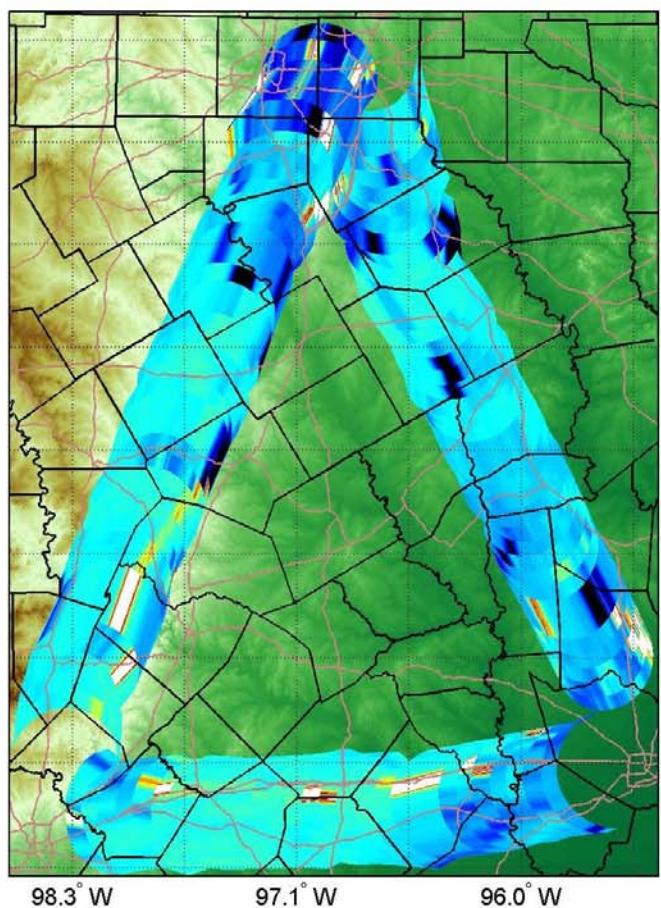


PSR/I L2.3 7.32h (B1 Ch7) April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 7.32h (B1 Ch7)L2.3 _{Front}



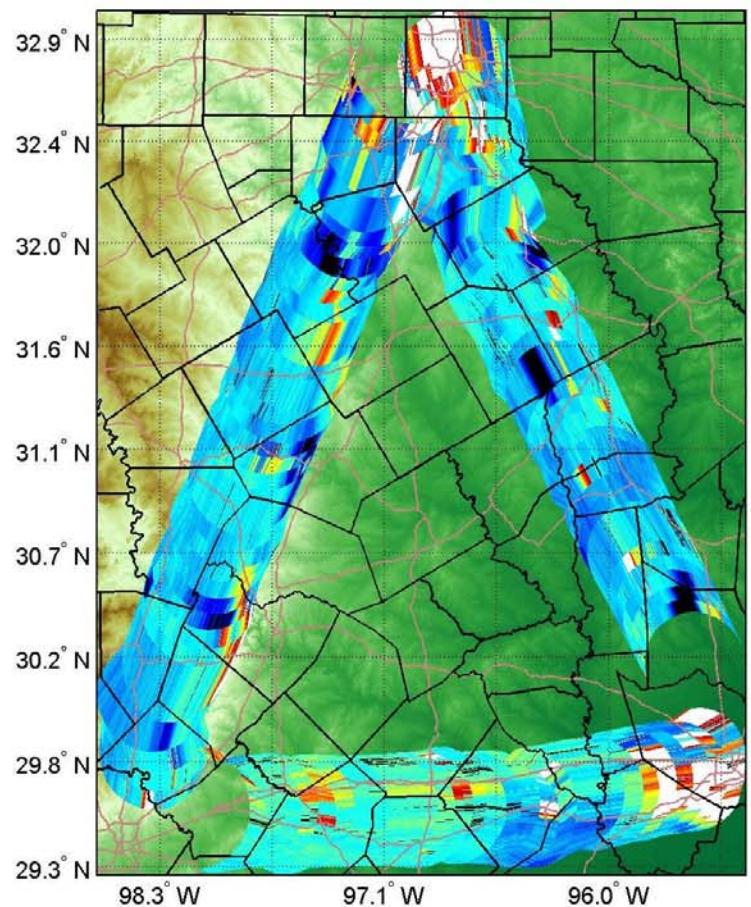
Houston, April 14, 2005: 7.32h (B1 Ch7)L2.3 _{Back}



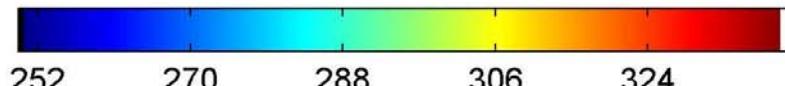
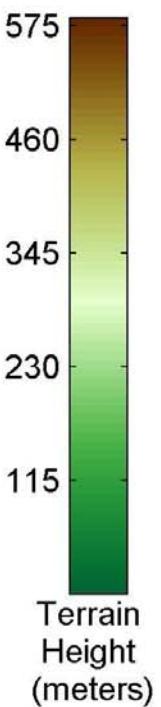
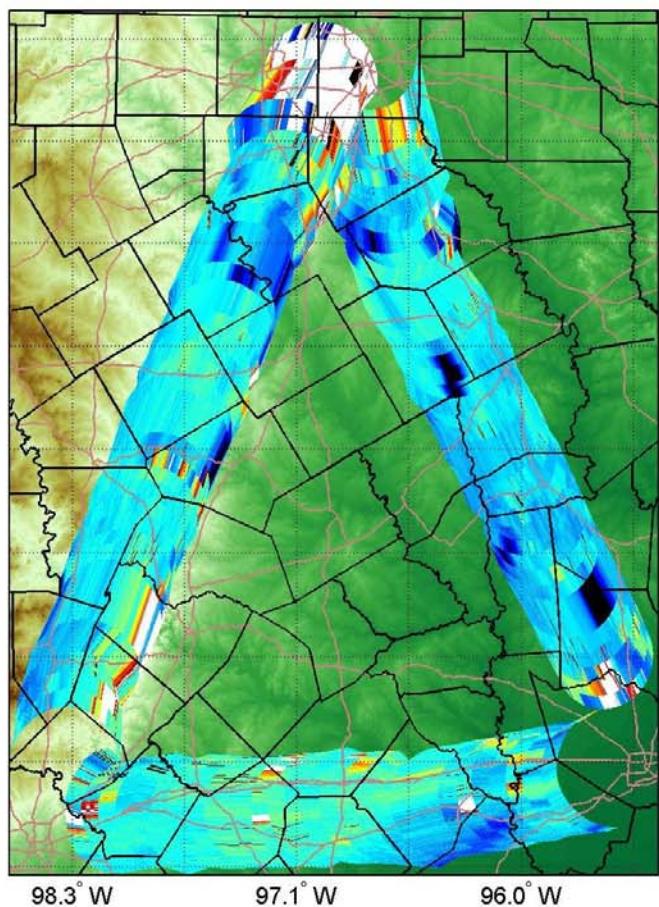
4-Subband Imagery - Corrected

PSR/I L2.3i 6.00h (B1 Ch1) Corrected April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.00h (B1 Ch1) CorrectedL2.3i _{Front}

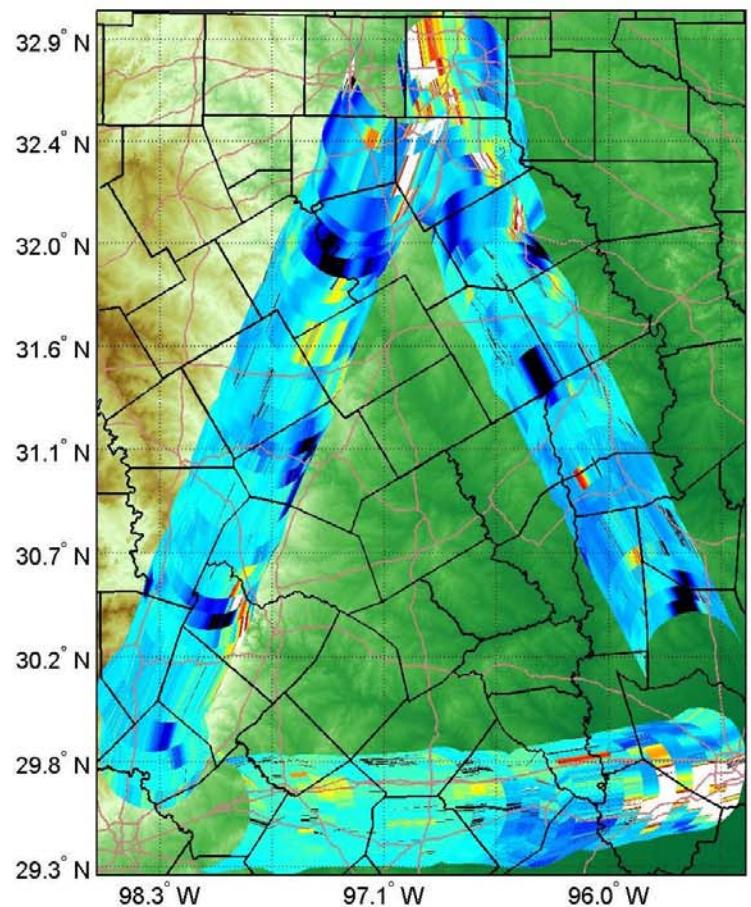


Houston, April 14, 2005: 6.00h (B1 Ch1) CorrectedL2.3i _{Back}

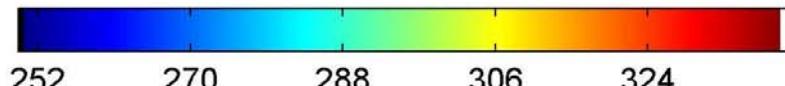
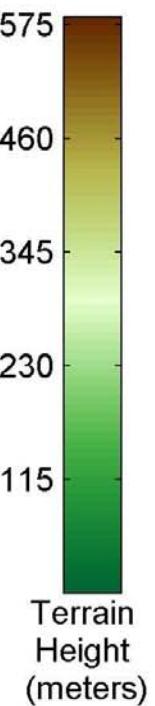
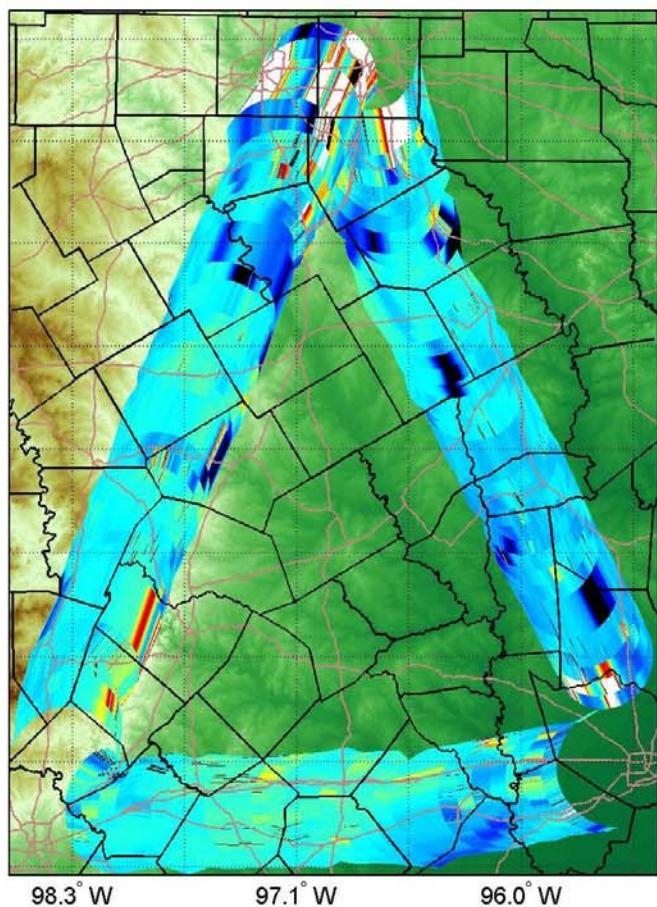


PSR/I L2.3i 6.50h (B1 Ch3) Corrected April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.50h (B1 Ch3) CorrectedL2.3i _{Front}

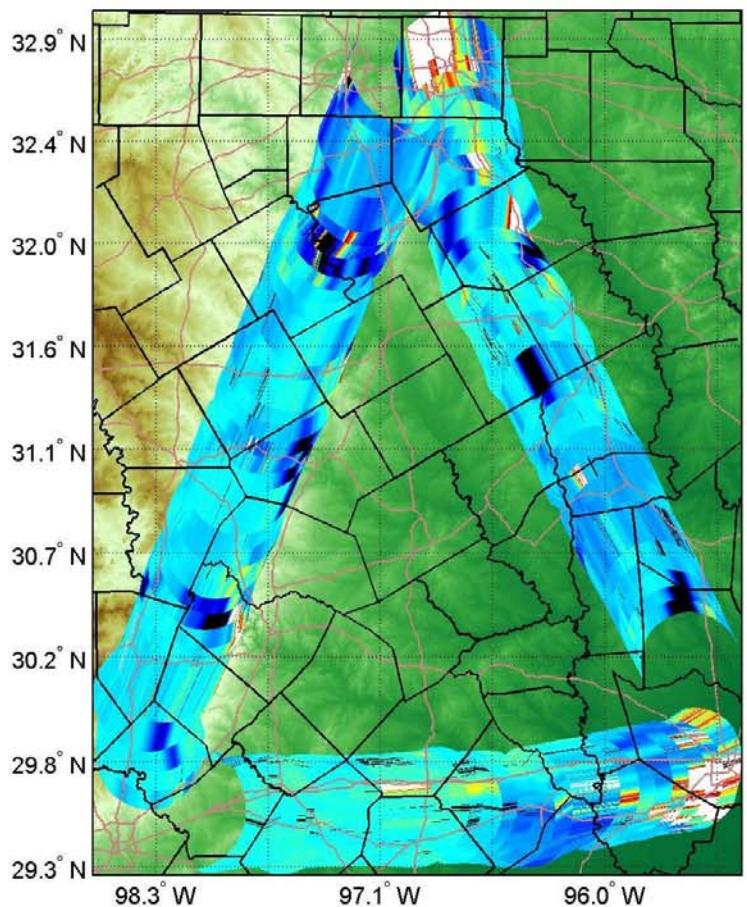


Houston, April 14, 2005: 6.50h (B1 Ch3) CorrectedL2.3i _{Back}

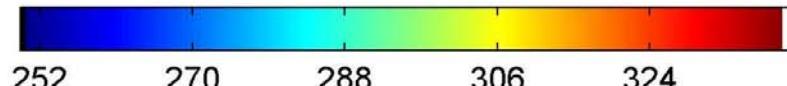
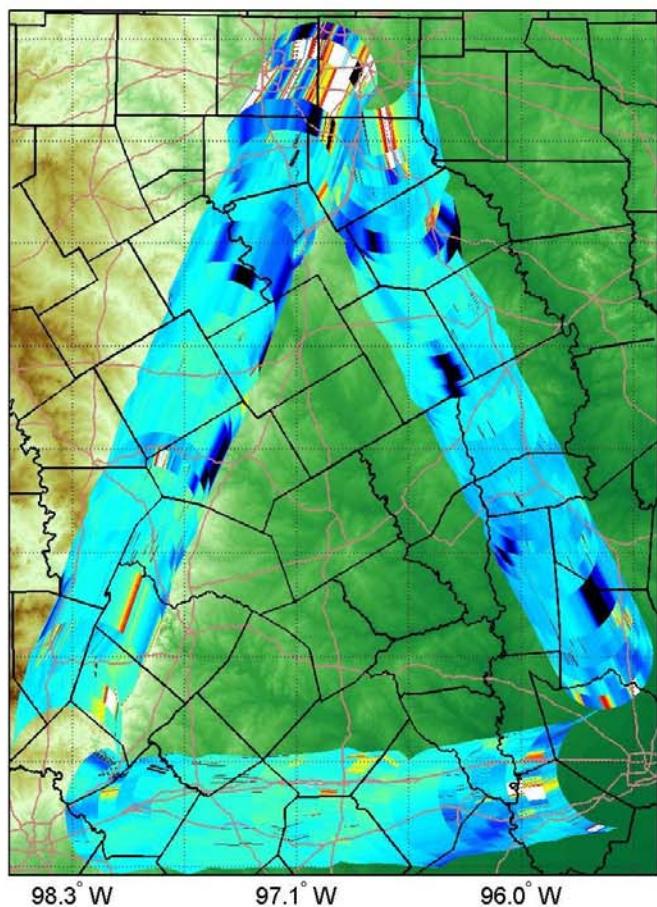


PSR/I L2.3i 6.92h (B1 Ch5) Corrected April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.92h (B1 Ch5) CorrectedL2.3i_{Front}

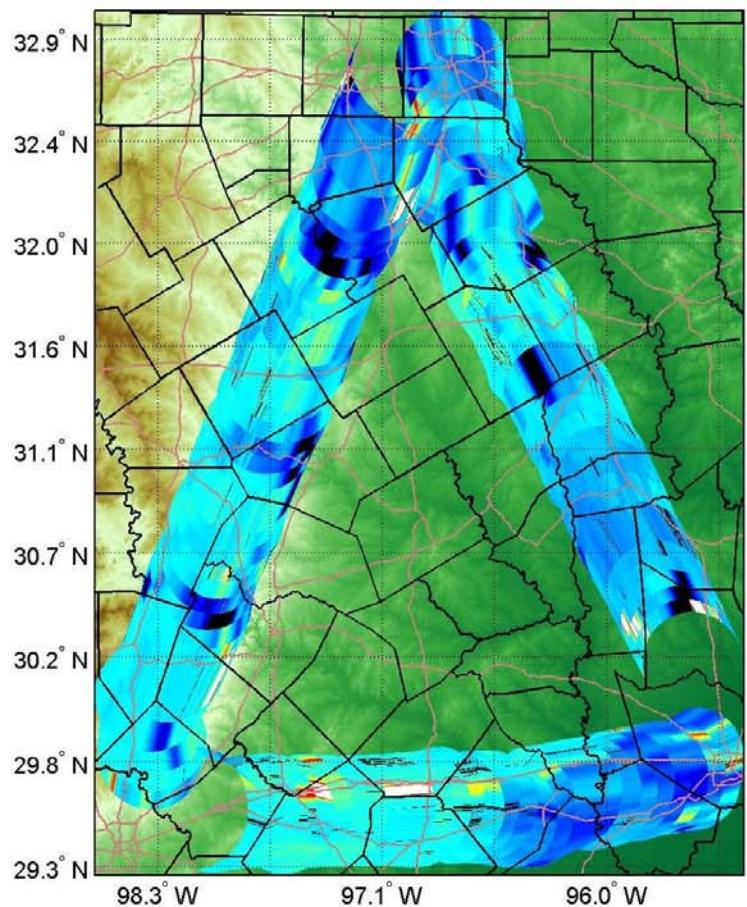


Houston, April 14, 2005: 6.92h (B1 Ch5) CorrectedL2.3i_{Back}

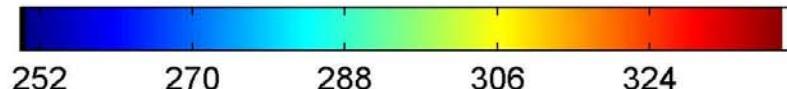
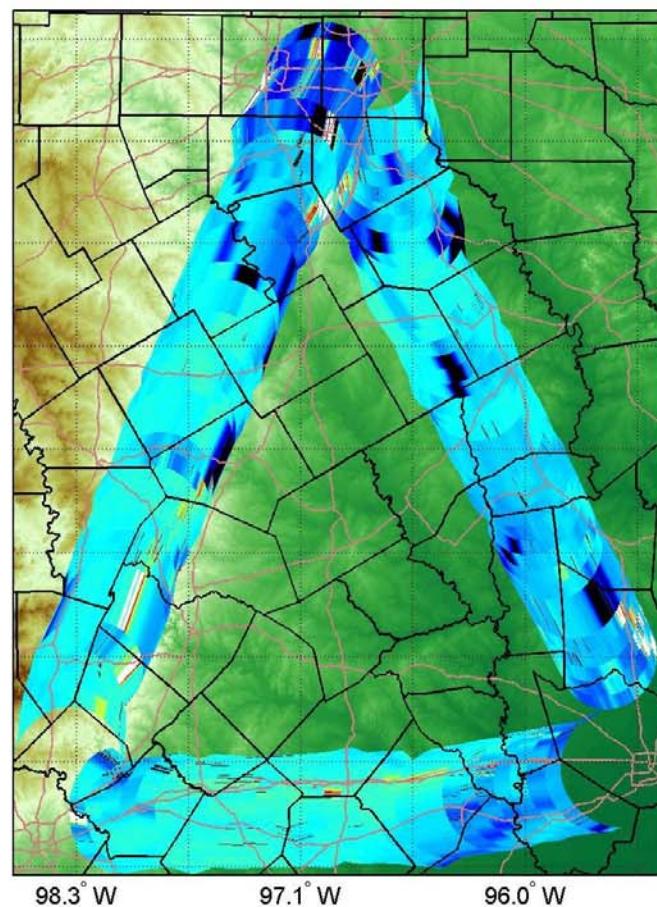


PSR/I L2.3i 7.32h (B1 Ch7) Corrected April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 7.32h (B1 Ch7) Corrected L2.3i _{Front}



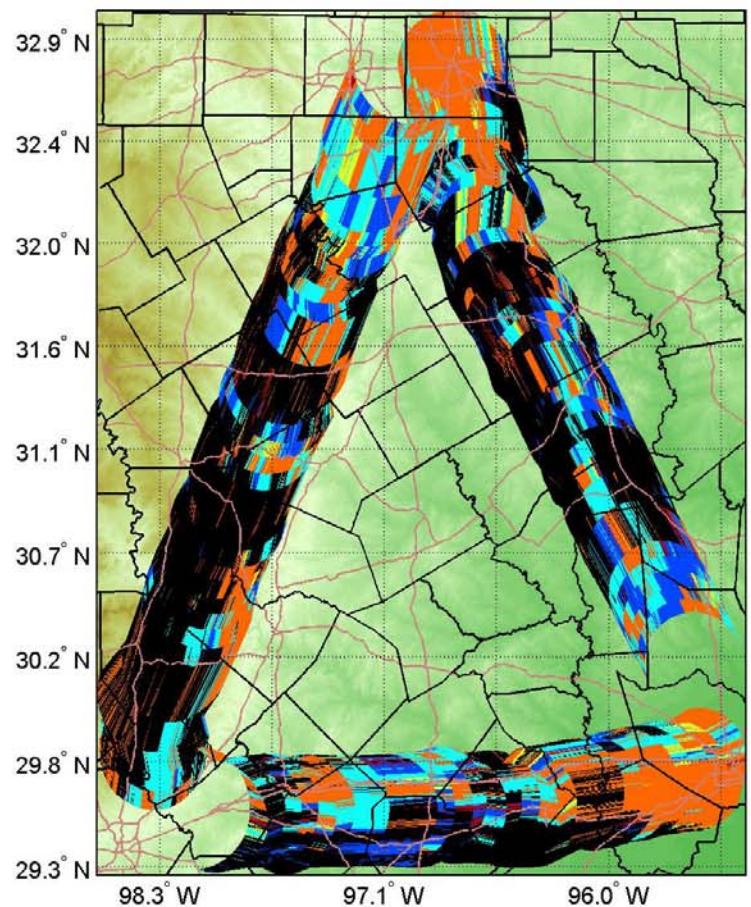
Houston, April 14, 2005: 7.32h (B1 Ch7) Corrected L2.3i _{Back}



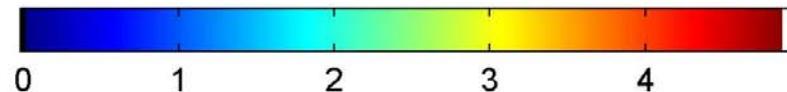
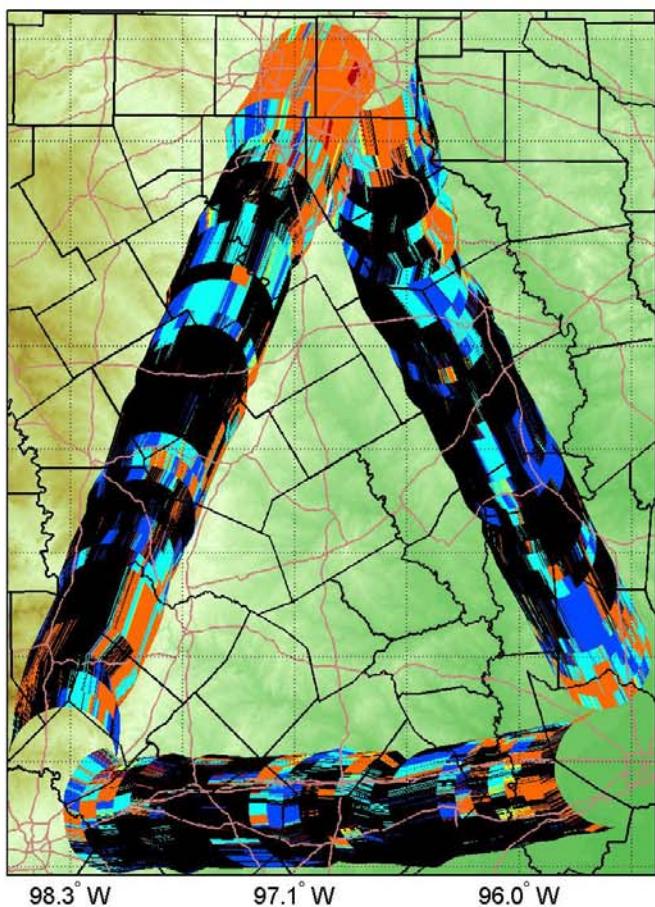
4-Subband Imagery - Severity

PSR/I L2.3i 6.00h (B1 Ch1) Severity April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.00h (B1 Ch1) SeverityL2.3i _{Front}

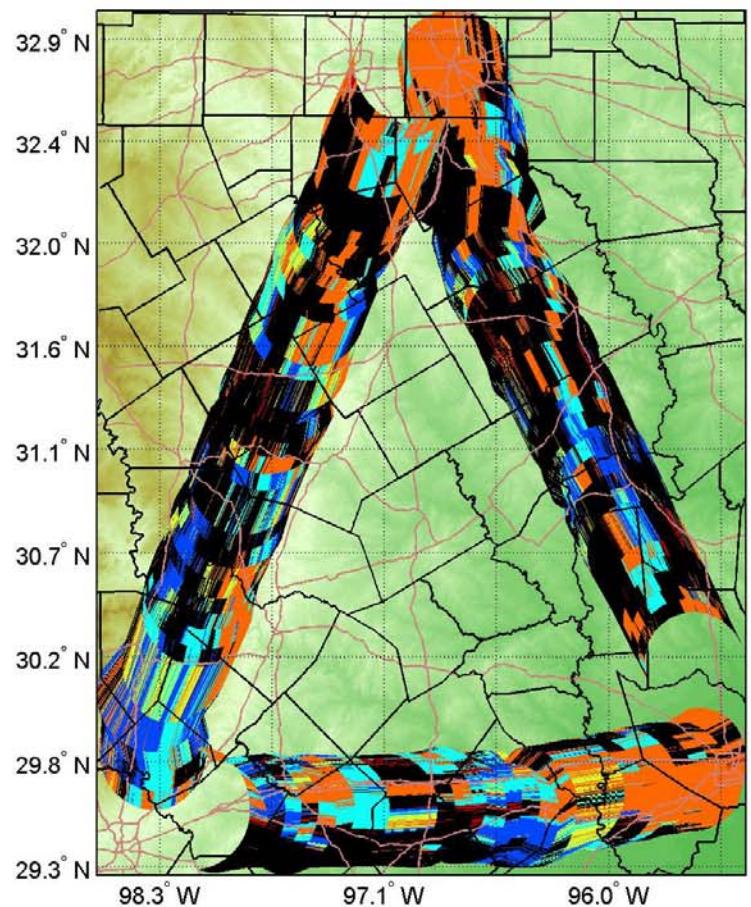


Houston, April 14, 2005: 6.00h (B1 Ch1) SeverityL2.3i _{Back}

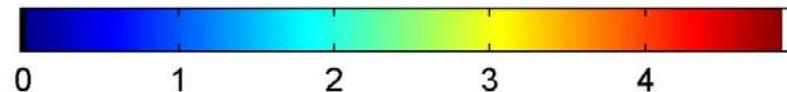
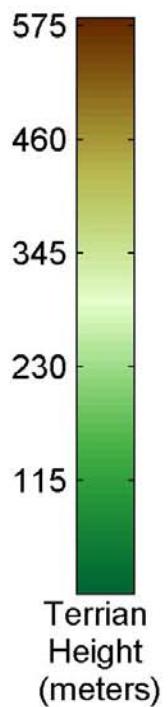
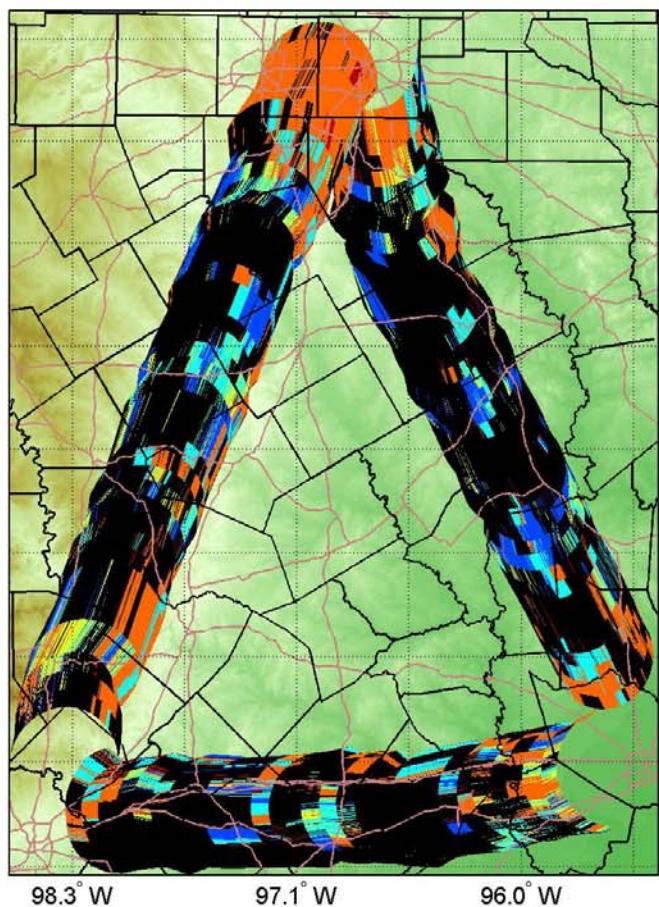


PSR/I L2.3i 6.50h (B1 Ch3) Severity April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.50h (B1 Ch3) Severity L2.3i _{Front}

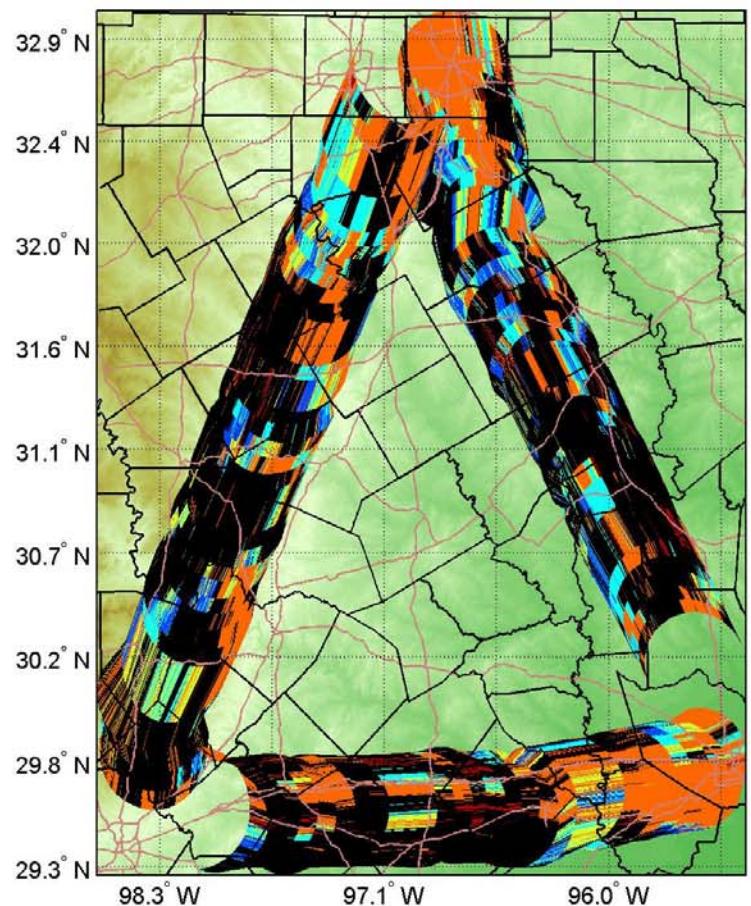


Houston, April 14, 2005: 6.50h (B1 Ch3) Severity L2.3i _{Back}

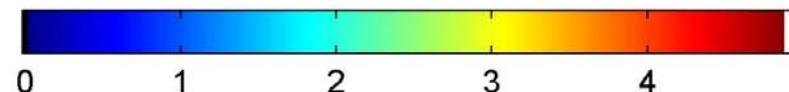
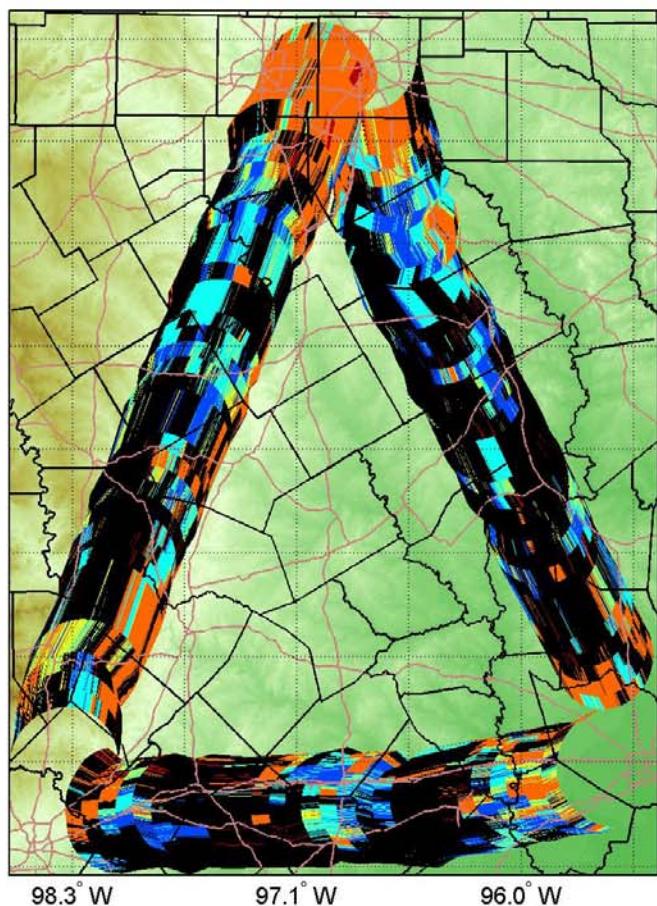


PSR/I L2.3i 6.92h (B1 Ch5) Severity April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 6.92h (B1 Ch5) Severity L2.3i _{Front}

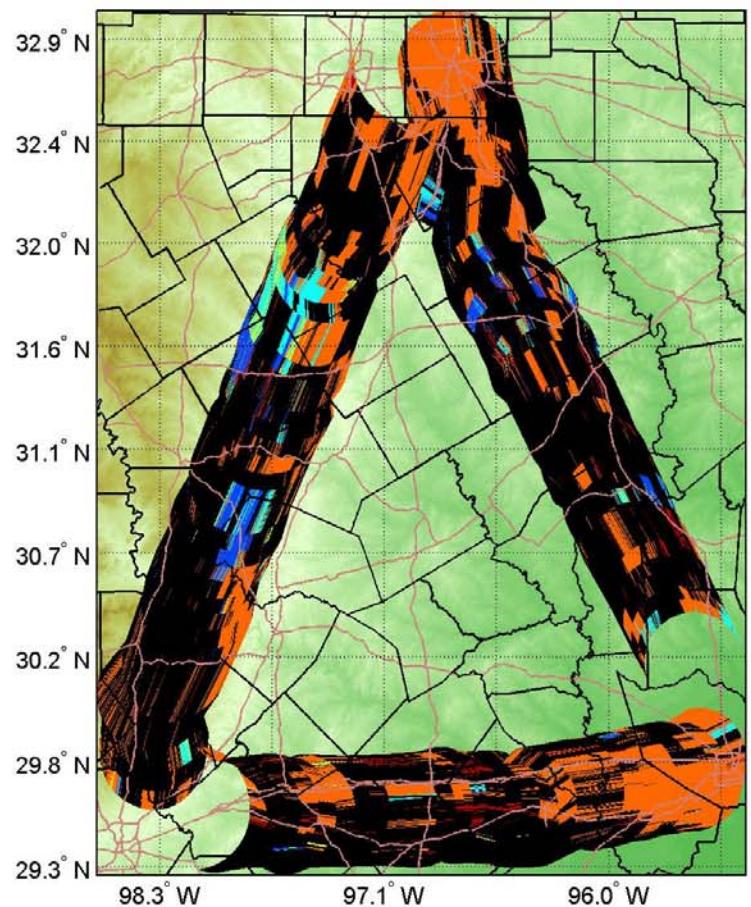


Houston, April 14, 2005: 6.92h (B1 Ch5) Severity L2.3i _{Back}

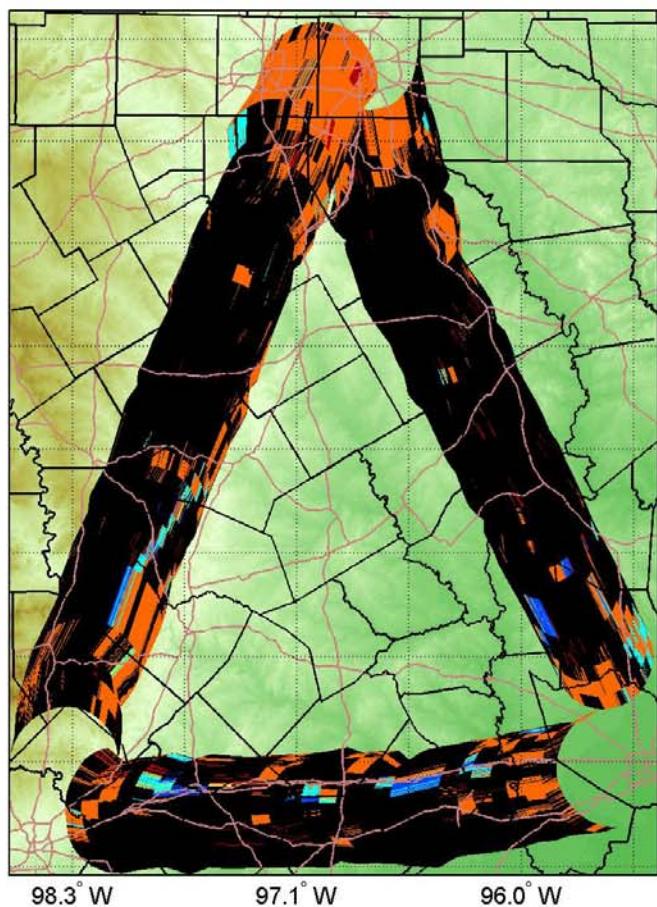


PSR/I L2.3i 7.32h (B1 Ch7) Severity April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 7.32h (B1 Ch7) Severity L2.3i Front



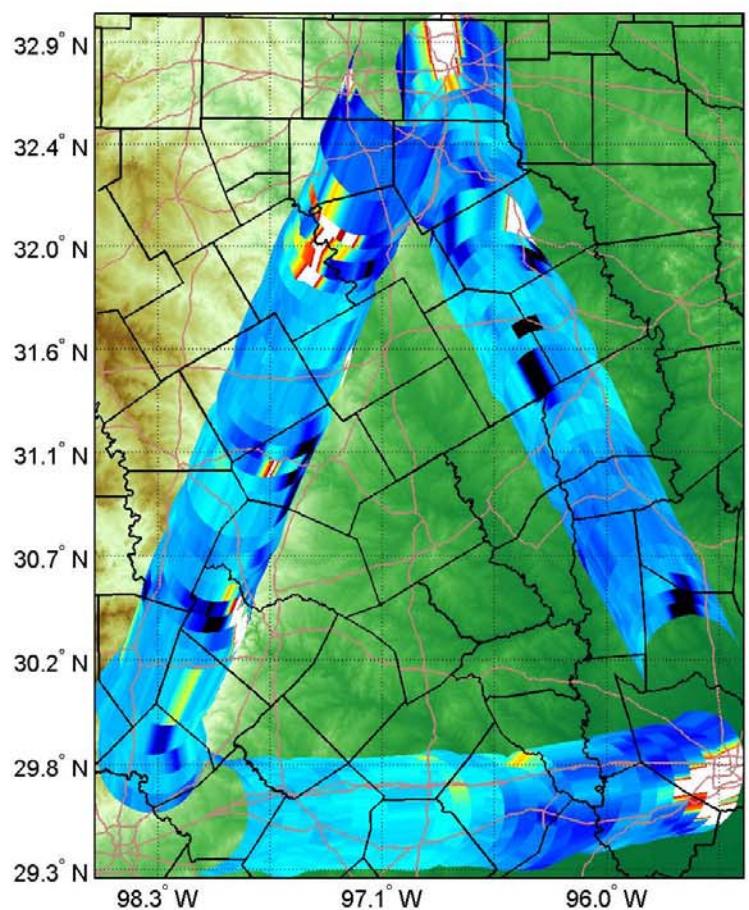
Houston, April 14, 2005: 7.32h (B1 Ch7) Severity L2.3i Back



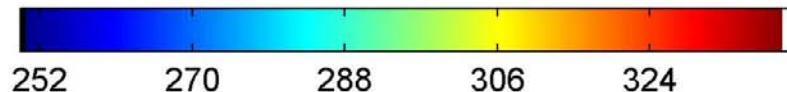
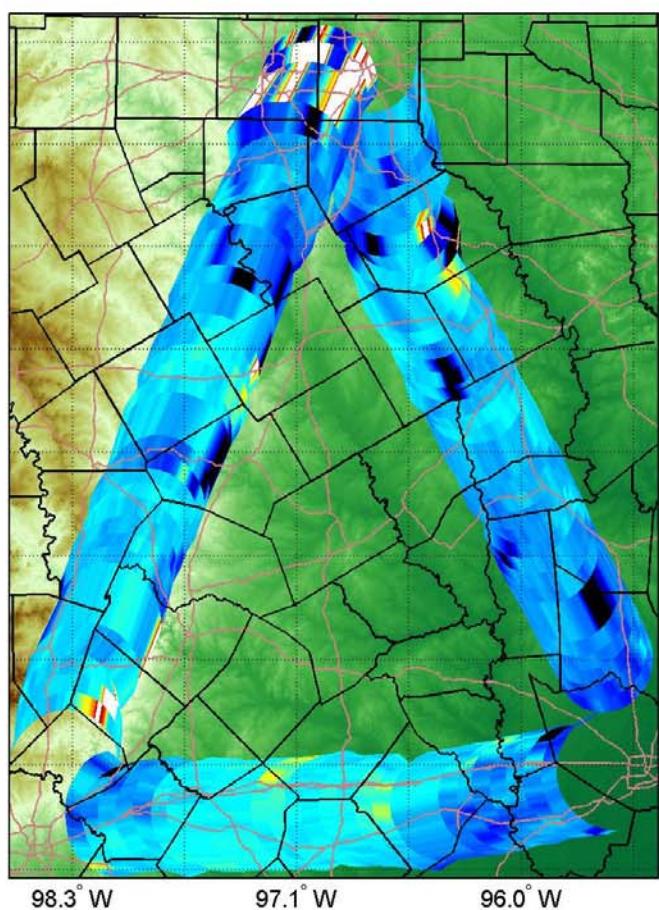
Spectrometer - Unmitigated

PSR/I L2.3 100hLin-(6949.9) April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 100hLin-(6949.9)L2.3 _{Front}



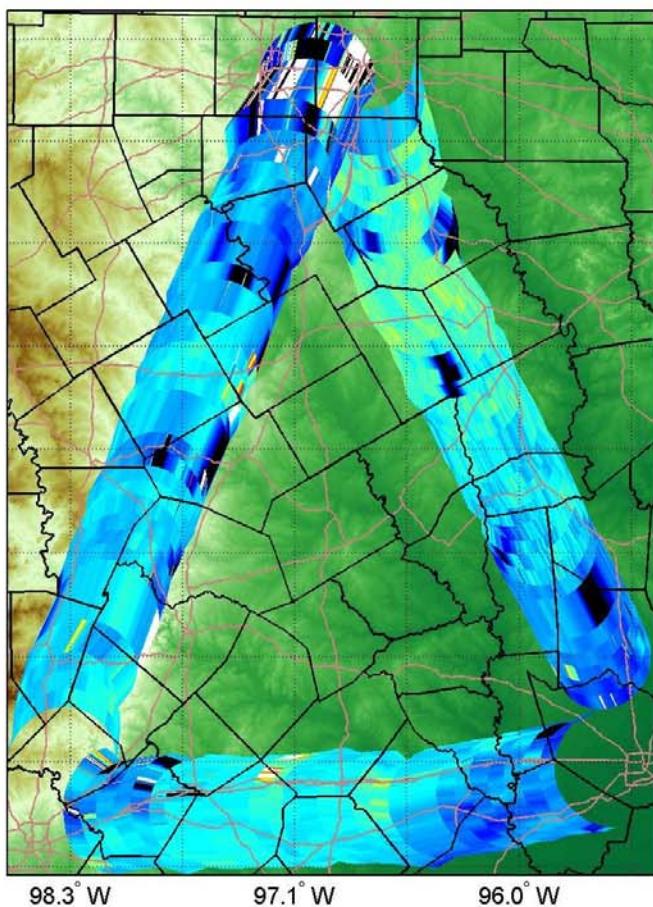
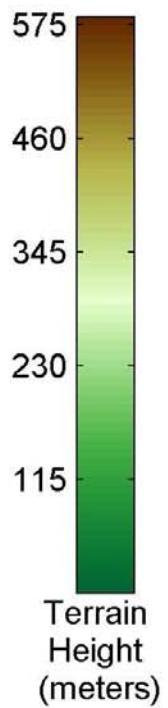
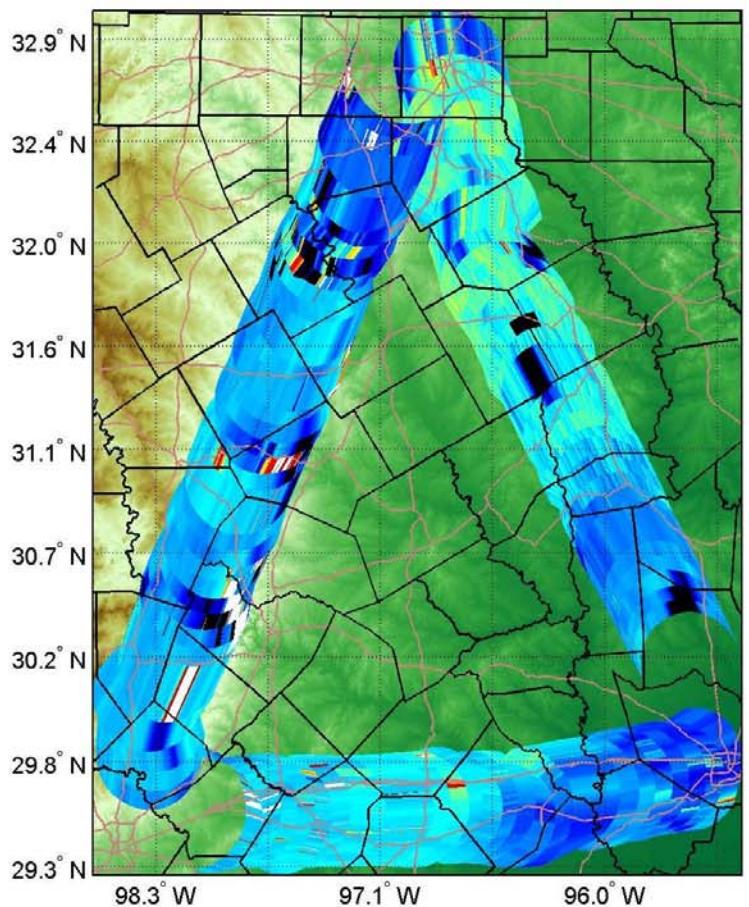
Houston, April 14, 2005: 100hLin-(6949.9)L2.3 _{Back}



Spectrometer - Corrected

PSR/I L2.3s 100hLin-(6949.9) Corrected April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

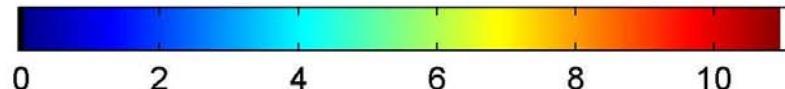
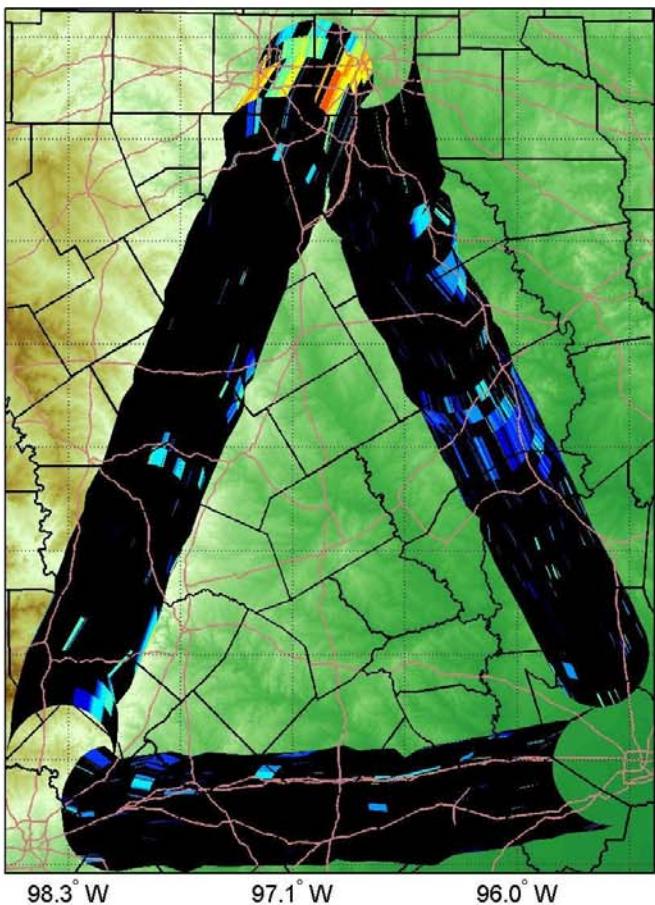
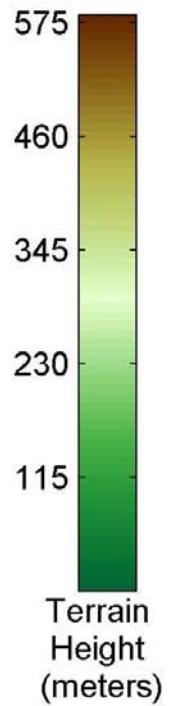
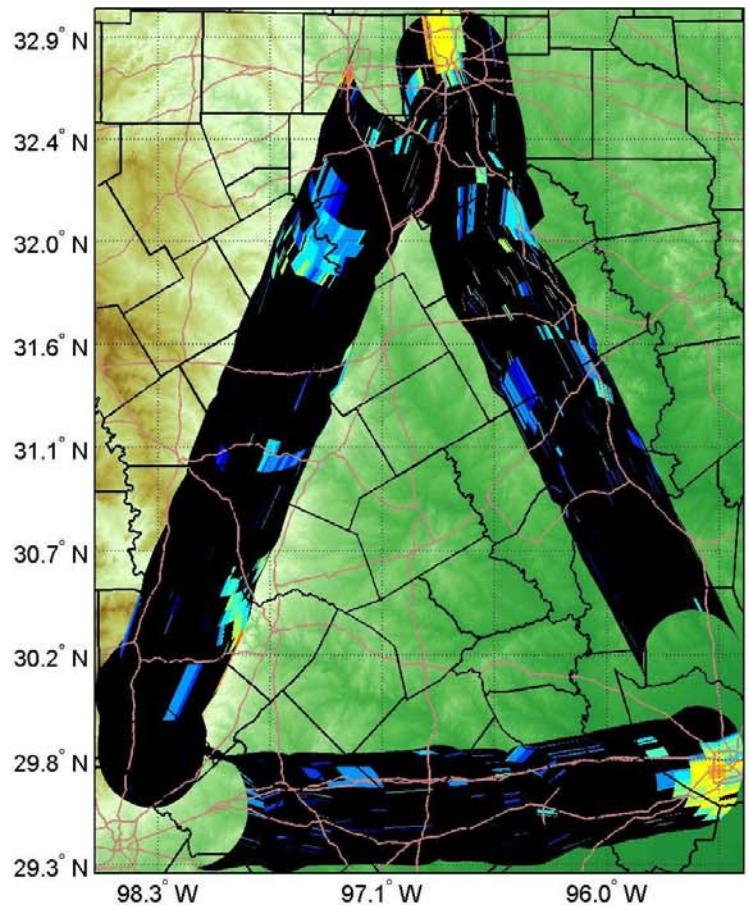
Houston, April 14, 2005: 100hLin-(6949.9) CorrectedL2.3s _{Front} Houston, April 14, 2005: 100hLin-(6949.9) CorrectedL2.3s _{Back}



Spectrometer - Severity

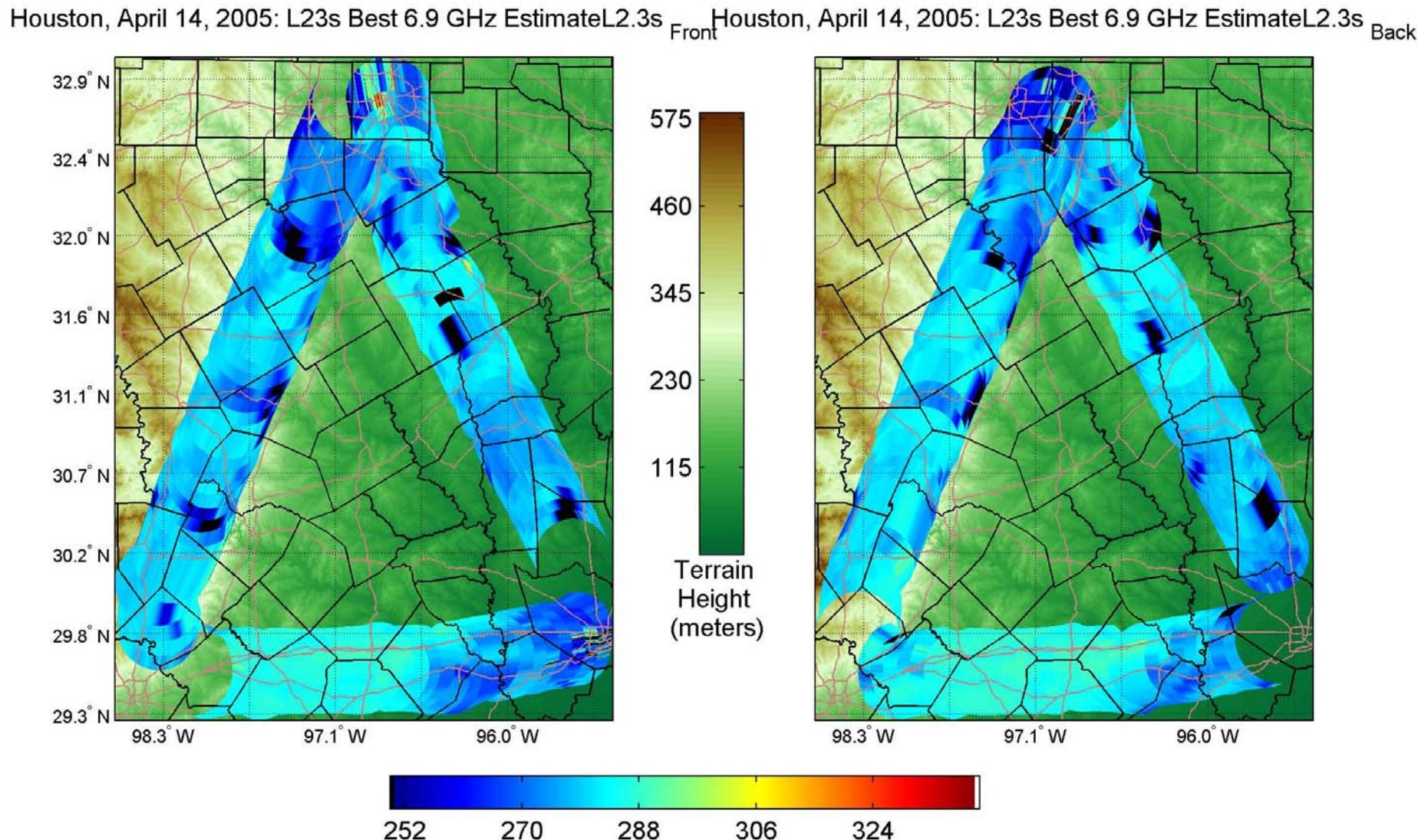
PSR/I L2.3s 100hLin-(6949.9) Severity April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

Houston, April 14, 2005: 100hLin-(6949.9) SeverityL2.3s _{Front} Houston, April 14, 2005: 100hLin-(6949.9) SeverityL2.3s _{Back}



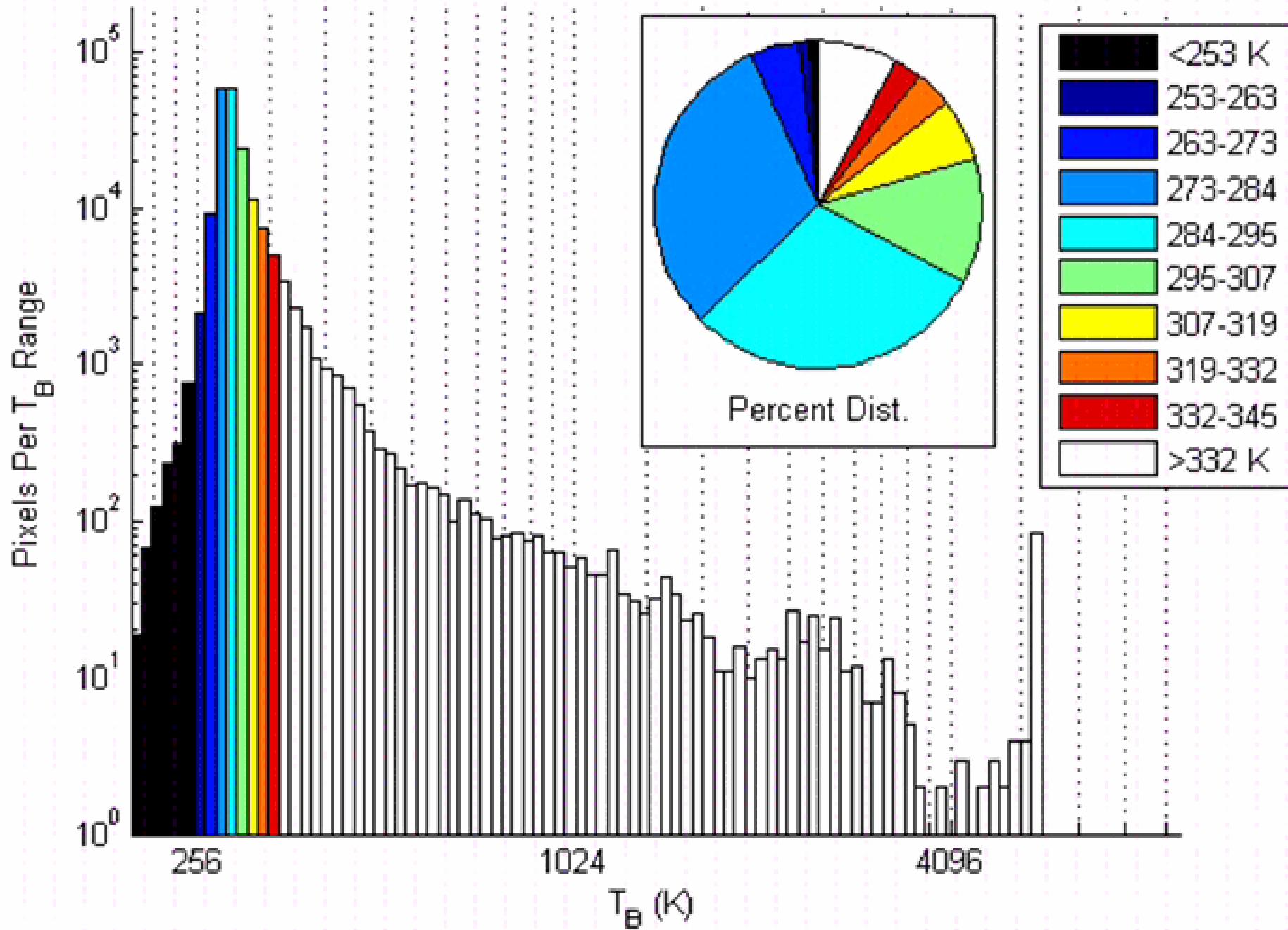
Spectrometer
Best Estimated Imagery

PSR/I L2.3s L23s Best 6.9 GHz Estimate April 14, 2005 Imagery:
WB05.DF001.C0100+0101+0102.SL.* - Scans 1 to 92 - Conical

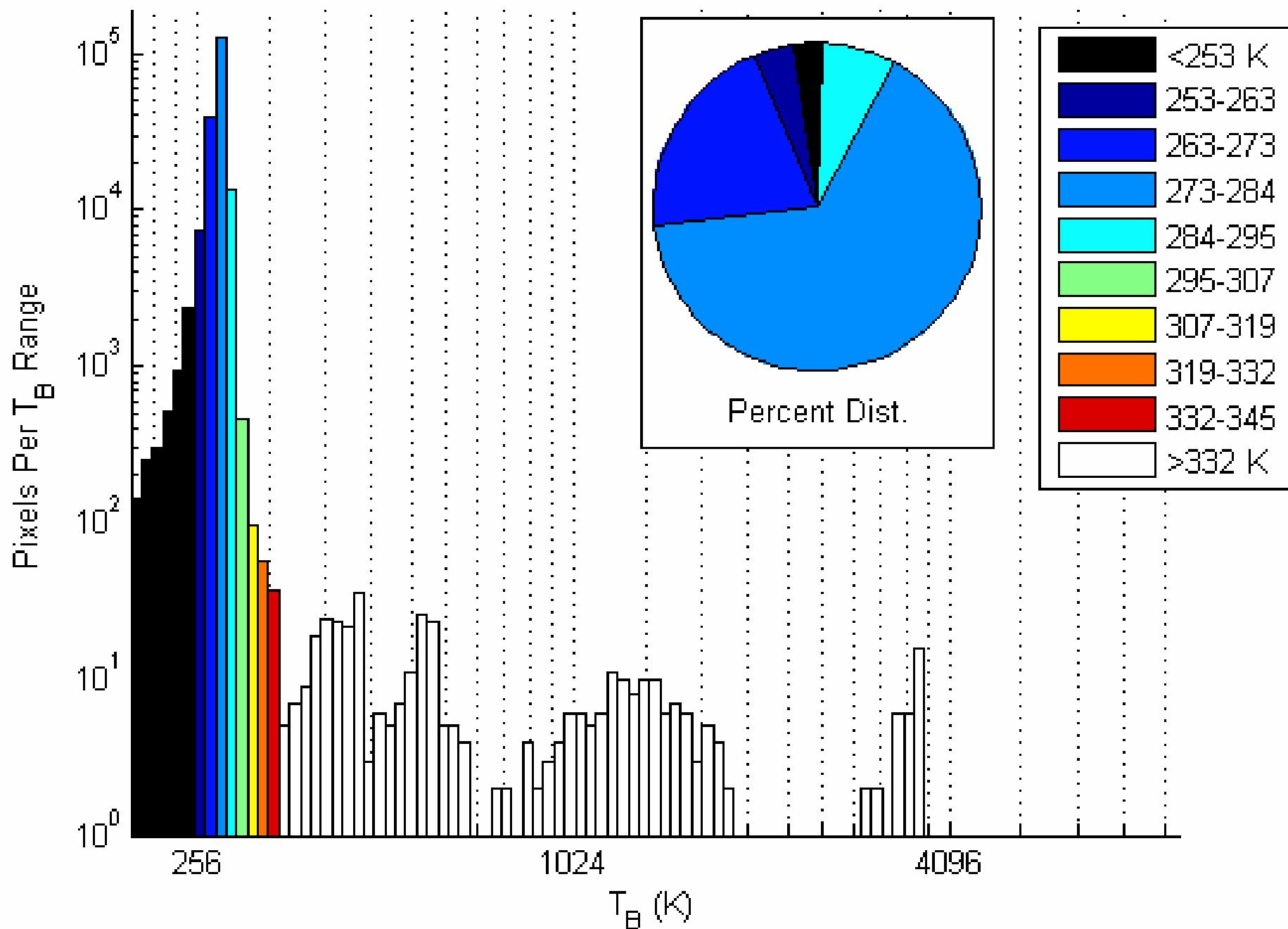


Corrected and Best Estimated Imagery at 6.92 GHz

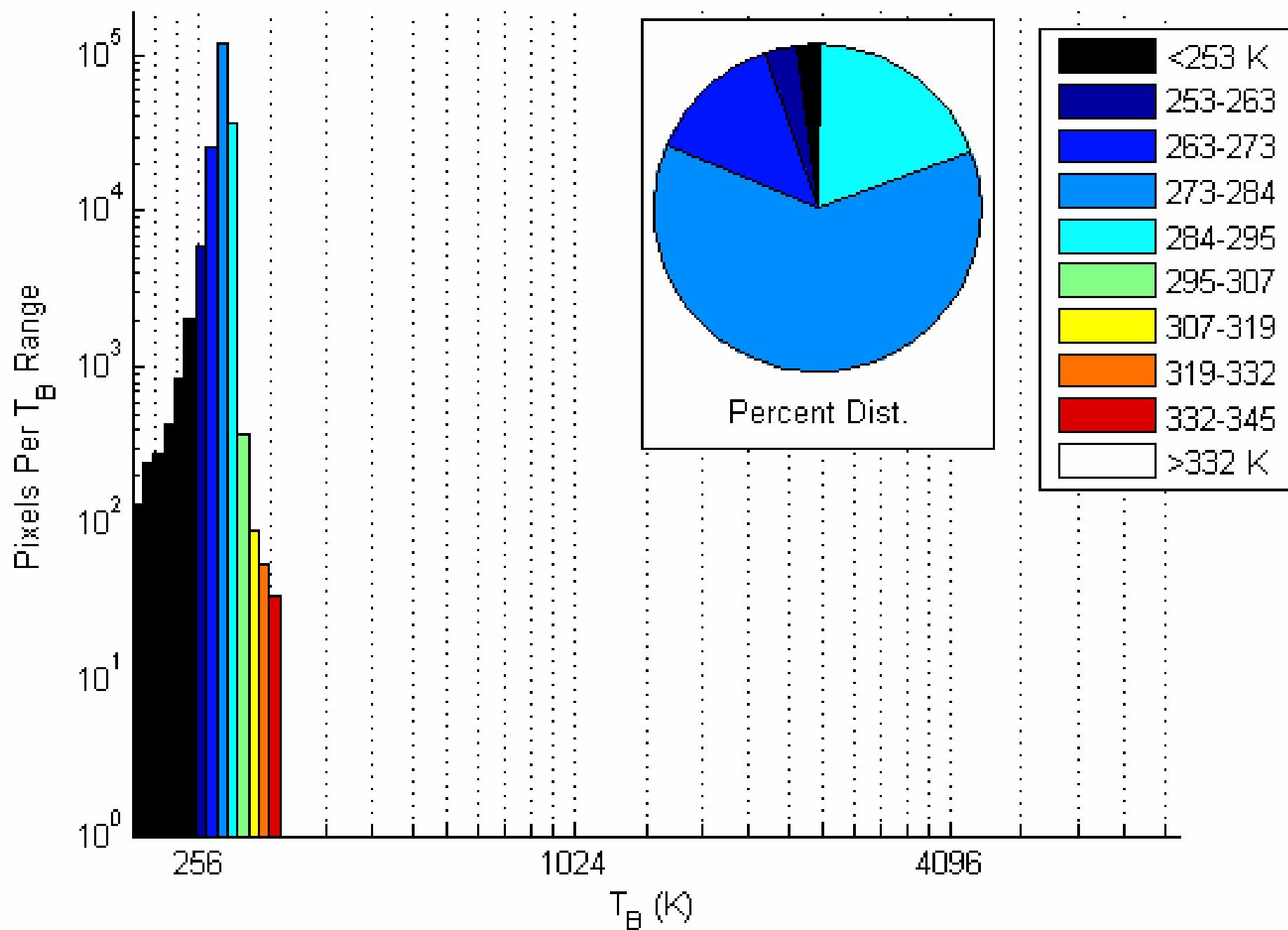
WBTEST05 - PSR/I L2.3 April 14, 2005 T_B Distribution - 6.00h (B1 Ch1)



WBTEST05 - PSR/I L2.3s April 14, 2005 T_B Distribution - 100hLin-(6949.9) Corrected



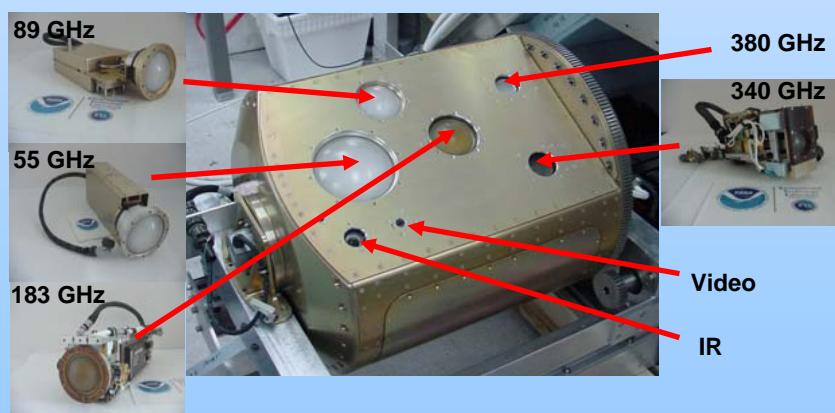
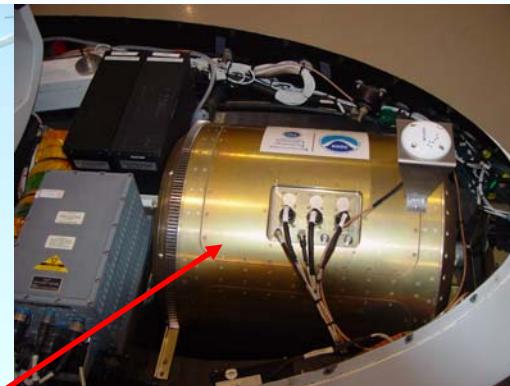
WBTEST05 - PSR/I L2.3s April 14, 2005 T_B Distribution - L23s Best 6.9 GHz Estimate



Summary – RF Interference

- Anthropogenic interference in passive microwave imaging is a growing problem, especially at L, C, X, and Ku bands.
- Effective and relatively inexpensive spectral interference mitigation techniques are possible - but certainly not as desirable as clean protected spectrum.
- Effective spectral interference mitigation has been demonstrated using airborne C-band imagery with both four discrete and multiple swept subbands.
- PSR semi – autonomous operation at high altitude demonstrated.

PSR/S on Altair





Atmospheric River Sounding Flight

- Weak Atm River Penetrated on May 9, 2005 -

